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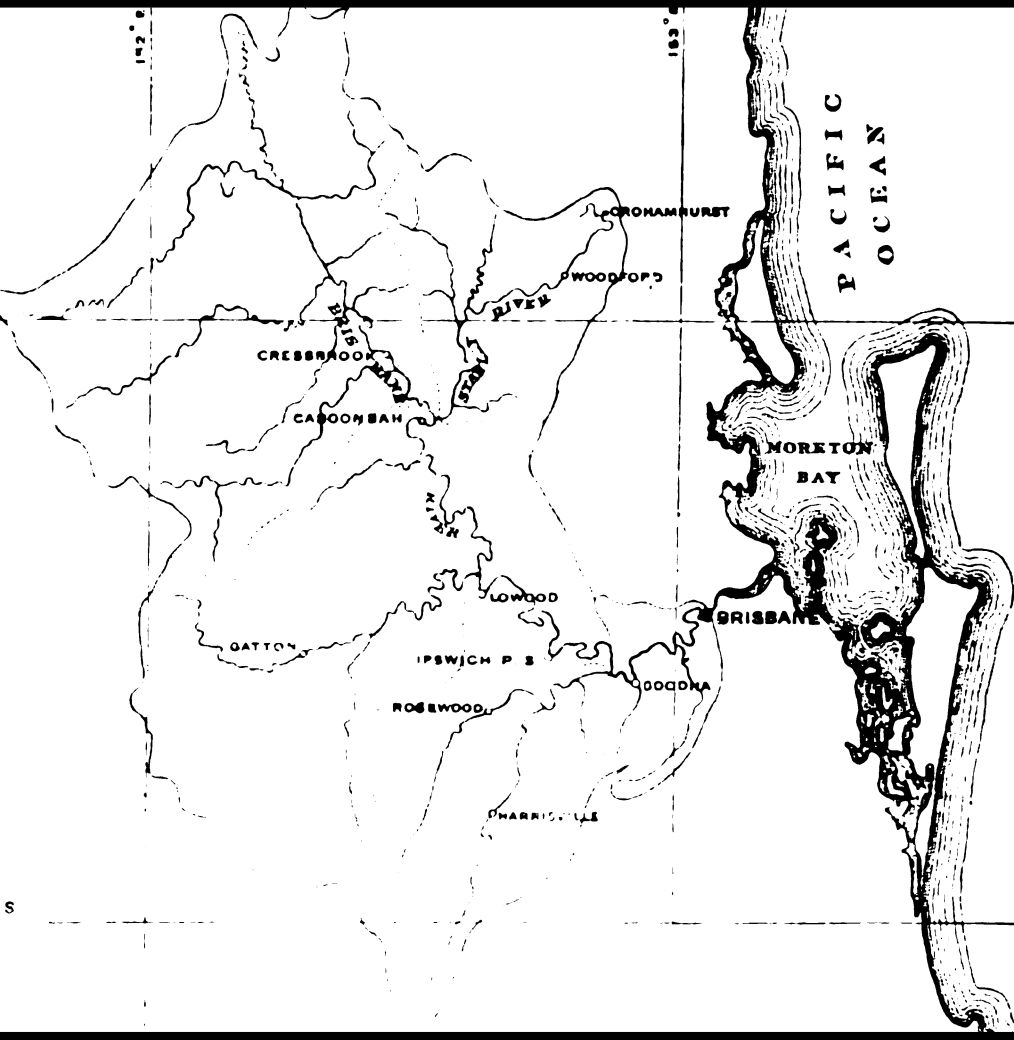

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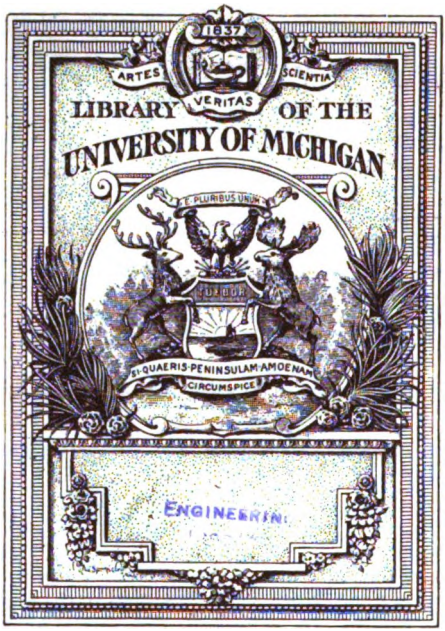

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MINUTES OF PROCEEDINGS

OF

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THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXXXVI.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. cxxxiv. p. 176, lines 1 and 2 from bottom, *for* "less than ten times the room of" *read* "less room than."
,, ,, p. 395, line 2, for "*cera perduta*" read "*cire perdue.*"
,, ,, p. 424, line 2 from bottom, *for* "second" *read* "minute."
,, cxxxv. p. 343, line 8, *for* "increases" *read* "decreases."

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1898-99.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

6 December, 1898.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

(*Paper No. 3138.*)

"The Ventilation of Tunnels and Buildings."

By FRANCIS FOX, M. Inst. C.E.

IN responding to an invitation to present to the Institution a Paper on the subject of ventilation, the Author has been impelled by his experience of the great evils which result from the apathy and ignorance so frequently displayed in regard to this question. No attempt is made to deal with the matter exhaustively, which would involve the introduction of many details which lie outside the province of the civil engineer; the Author therefore trusts that, in this respect, the Paper will evoke discussion by those who can deal more fully with points which are only incidentally referred to by him.

The principles of ventilation as adapted to coal and metalliferous mines have been fully considered and applied by members of the mining branch of the engineering profession. Furnaces were formerly universally employed for causing an ascending current in the upcast shaft; but these, except in some very deep mines, where the column of heated air possesses considerable power, have given place to mechanically-driven fans placed at the top of the up-cast shaft. This shaft is also available for winding, an arrangement being provided by which the top of the shaft is opened and closed for the passage of the corves or trucks without interfering with the steady work of the fan. The fans vary in design, in size and in speed of revolution, but the Author does not propose to discuss the merits of the various types in use. He feels strongly that had civil engineers and architects applied to all the works under their care the rules

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and regulations observed by mining engineers, they would not now in many cases be confronted with the evils with which in the Paper it is intended to deal.

The subject may be treated under two heads, relating respectively to railway tunnels and to buildings.

Ventilation of Railway Tunnels.

The ventilation of railway tunnels was dealt with by Mr. Gabriel James Morrison in a Paper[1] read before the Institution in 1876, entitled "The Ventilation and Working of Railway Tunnels," and in a Paper[2] by the Author on "The Mersey Railway," read in 1886. Reference has also been made by the late Mr. Harrison Hayter[3] to the ventilation of the Severn Tunnel. The principle hitherto acted upon, where mechanical ventilation has been adopted, has been to exhaust the vitiated air at a point midway between the portals of a tunnel, by means of a shaft with which is connected a ventilating fan of suitable power and dimensions. In the case of the tunnel under the River Mersey, such a shaft could not be provided, owing to the river being overhead, but a ventilating heading was driven from the middle of the river (at which point entry into the tunnel was effected) to each shore, where a fan, 40 feet in diameter, was placed. By these means the vitiated air is drawn from the lowest point of the railway, and fresh air flows in at the stations on each side, to replenish the partial vacuum. In the Severn Tunnel, owing to the middle of the length of the tunnel being nearly at the Gloucestershire side of the river, a vertical shaft is sunk to the tunnel, and a fan, 45 feet in diameter, extracts the vitiated air at this point.

Objection has been taken to this system of placing fans midway between the entrances of a tunnel, as being liable to be affected by a strong wind blowing in at either end. There is some ground for this contention, but the late Mr. Hayter[4] stated to the recent Departmental Committee of the Board of Trade that the only difference he observed was that the speed of the air travelling to the fan was about 1 mile per hour less in one direction than in the other. It may also be noticed that when a strong wind is blowing into a tunnel, no artificial ventilation is

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[1] Minutes of Proceedings Inst. C.E., vol. xliv. p. 18.

[2] *Ibid*, vol. lxxxvi. p. 40. [3] *Ibid*, vol. cxi. p. 6.

[4] "Report of the Committee appointed by the Board of Trade to inquire into the System of Ventilation of Tunnels on the Metropolitan Railway. . . . Minutes of Evidence," 1897, p. 38.

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required, and the fan may be stopped with advantage. It is when the air in the tunnel is stagnant, or is moving very slowly, that mechanical aid is required, and a fan of suitable size and power effectually accomplishes the result desired. The Author has by inquiry and by personal experience ascertained that if the amount of carbon dioxide can be kept low, so as not to exceed 20 parts in 10,000, the air in a tunnel is satisfactory.

The consumption of coal by a locomotive during the passage through a tunnel having been ascertained, allowing 29 cubic feet of poisonous gas for each pound of coal consumed, the volume of fresh air required to maintain the atmosphere of the tunnel at the above-mentioned standard of purity is ascertained as follows:— The number of lbs. of fuel consumed per mile, multiplied by 29, multiplied by 500, and divided by the number of minutes' interval between the trains, will give the volume of air in cubic feet which must be introduced into the tunnel per minute to maintain it in a sufficiently pure state to avoid inconvenience.

As an illustration, assume that the tunnel is 1 mile in length, and the consumption of fuel is 32 lbs. per mile, and that one train passes through the tunnel every 5 minutes in each direction, the volume of air required per minute will be:—

$$\frac{32 \text{ lbs.} \times 29 \text{ cubic feet} \times 500}{2\frac{1}{2} \text{ minutes}}$$

$$= 185{,}600 \text{ cubic feet};$$

the air will then be maintained at a standard of purity in which the carbon dioxide does not exceed 20 parts in 10,000.

This is the basis upon which the Mersey and the Severn Tunnels are ventilated, and which have been shown,[1] by the Report of the Committee referred to, to be efficiently supplied with fresh air; it is, however, to be regretted that, in the case of the Mersey Tunnel, owing to the impecuniosity of the Company, inferior coal is now used, and the fans are driven at a lower speed than was intended. The airways then become encrusted with soot, which in some places is between 2 inches and 3 inches in depth; but, notwithstanding these drawbacks, the examination of the air of the tunnel, made by Dr. John Haldane, F.R.S., for the Departmental Committee, showed[2] that the amount of carbon dioxide was considerably less than 20 parts in 10,000. There is

[1] "Report of the Committee appointed by the Board of Trade to inquire into the System of Ventilation of Tunnels on the Metropolitan Railway. . . . . Minutes of Evidence," 1897, p. 8.

[2] *Ibid*, p. 120.

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no doubt that this tunnel, when proper coal is used and the fans are run at the intended speed, is the most perfectly ventilated tunnel of its kind in the world.

With the Metropolitan Railway the Author does not intend to deal, as it has been the subject of recent investigation. The amount of carbon dioxide is, however, very high, reaching sometimes as much as 86 parts in 10,000. It is, however, only fair to point out that fan ventilation on that railway has never been practically adopted, the fans which were fixed being of insufficient size and power to produce any important effect on the air of the tunnel.

The Mont Cenis Tunnel is about 8¼ miles in length and 26 feet in width, and, in consequence of the mountain above it, possesses no shaft. The construction is of excellent character, the tunnel being lined throughout with masonry or brickwork, except two lengths of 330 feet and 260 feet respectively. In these two lengths solid white quartz was encountered, which occupied years to penetrate. Owing to an alteration during construction, on the Italian side, the Bardonecchia entrance is at a considerably lower level than that originally intended, necessitating the introduction of an ascending gradient of 1 in 40 for a length of about 1,000 yards from the portal. The tunnel is then nearly level for about 3½ miles, when a descending gradient of about 1 in 40 occurs for nearly 4 miles towards the French side. The higher altitude of the middle of the tunnel above its entrances has compromised its ventilation, and sometimes great difficulty is experienced in carrying on the traffic. At the Bardonecchia entrance there is a somewhat obsolete installation of seven overshot water-wheels, 5 metres in diameter, and 6 metres in length on the breast, over which in succession a mountain stream is conducted. These wheels work air-compressors, the air being delivered under a pressure between 4½ and 6 atmospheres, and discharged at points 1 kilometre apart throughout the tunnel. The quantity of air is so small that for purposes of tunnel ventilation it has little effect, amounting only to 70 cubic metres per minute of air at 75 lbs. pressure per square inch; but it is of great advantage to the men employed in the tunnel. At intervals of 1 kilometre there are refuges for the men, supplied with fresh air, water and a telephone. Into these chambers the men can retire when the smoke is thick, and there wait for an engine to take them out. The corrosion of rails is very rapid, and, were proper ventilation provided, it would not only be of the greatest comfort to the men, but the life of the rails would probably be doubled.

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About 300 tons of rails have to be relaid every year, so that, were their life doubled, a saving of 150 tons would be effected annually, which would probably far more than pay for efficient ventilation. The Author is informed that a preservative against rust is now being used, but with what result he is not aware. The temperature of the middle of the tunnel remains nearly constant during summer and winter, and is about 66° to 68° F.

The St. Gothard Tunnel is 9½ miles in length, and 26 feet in width; it is nearly level from end to end, the gradient being only that needed for drainage purposes. The ventilation was entirely natural until recently; but, owing to the use of briquette fuel, with its dense smoke, and to the constant increase of the traffic, a time arrived when it was necessary that something should be done, and recently the Saccardo system has been adopted.

In long tunnels on steep gradients, such as exist in Italy and elsewhere, artificial ventilation is imperatively needed. In the cases of the Pracchia Tunnel, 3,000 yards in length on a gradient of 1 in 40; the Mont Cenis Tunnel, with its peculiar longitudinal section, described above, with gradients of 1 in 40 at both ends; the spiral tunnels, with gradients of 1 in 40, on the St. Gothard route, and the long tunnel of Ponte Decimo near Genoa—grave inconvenience and even worse results arise. Asphyxiation is not unknown, and the loss of life attending the collision of the 11th August, 1898, at the mouth of the last-named tunnel, in which twelve persons were killed and forty injured, was the direct result of bad air.

The case of the Pracchia Tunnel is interesting. It is one of fifty-two tunnels on the main line between Florence and Bologna, built by the late Mr. Thomas Brassey, Assoc. Inst. C.E. These are single-line tunnels, on a gradient of 1 in 40. The traffic has increased greatly and has to be worked by heavy locomotives. Under any condition of wind the state of this tunnel, about 3,000 yards in length, is bad; but, when the wind is blowing in at the lower end at the same time as a heavy goods or passenger train is ascending the gradient, an almost insupportable state of affairs is produced. The engines, which are working with the regulators full open, often emit a large quantity both of smoke and steam, which travels concurrently with the train. The locomotives weigh 55 tons without tender. They have eight wheels coupled, with a tractive force of 15,400 lbs. The goods trains carry 250 tons of load and have an engine in front and one at the rear of the train; and when, from the humidity in the tunnels due to the steam, the wheels slip and possibly the

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train stops, the condition of the air is indescribable. A heavy train with two engines, conveying a Royal party and their suite, arrived on one occasion at the upper exit of the Pracchia Tunnel with both engine-men and both firemen insensible; and on another occasion, when a heavy passenger train came to a stop in the tunnel, all the occupants were seriously affected. On the occasion of the Author's visit to the tunnel, on the 25th July, 1894, one of the brakesmen complained of being ill and of having fallen from his seat in one of the shorter tunnels.

The Saccardo system of ventilation has just been applied to the Pracchia Tunnel with remarkable results. Mr. Marco Saccardo, the well-known Italian engineer, avails himself of the annular space between the interior surface of the tunnel and the gauge of maximum construction, and, upon the principle of the injector, blows, by means of a fan, a large volume of air into the tunnel at its mouth. This induces a strong inward current at the central opening, through which the trains pass. The Author measured the volume and temperature of air with the following result. Before starting the fan, the tunnel was filled with dense smoke from end to end, the temperature being 107° F., with 97 degrees of moisture, or nearly complete saturation. With the fan running, the thermometer indicated 80° (the temperature of the external air), or a fall of 27°, the moisture was normal, and the amount of air propelled by the fan was 164,000 cubic feet per minute, that by the induced current being 46,000 cubic feet, making a total of 210,000 cubic feet of air per minute passing through the tunnel. The air is blown in at the upper end, and down the incline, the object being that an ascending train with its heavy trail of smoke and steam may be freed at the earliest possible moment from the products of combustion. These results are remarkable, and the air of the tunnel is cool and fresh. This system, however, cannot be applied to railways in which underground stations exist, as the effect of the current would be to blow the smoke to the platforms of the next station, the very part of the railway which should be kept in the best condition.

The Simplon Tunnel, now under construction, will be 12¼ miles in length, and will consist of two parallel tunnels, at a distance of about 50 feet apart from centre to centre. The gradient from Brigue is only 1 in 500, and this for drainage purposes for a distance of 6¼ miles; thence the rails will fall on a gradient of 1 in 142 for the remaining 6 miles to the Italian portal. The ventilation of this tunnel has been very carefully considered, and although it is not definitely decided which system is to be adopted,

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it is not improbable that the Saccardo system will be selected, as in those cases where shafts are not available, it is the only one that can be advantageously employed. Even where shafts exist, and there are not intermediate stations, it is probably the most effective and economical method.

In the near future it is not improbable that the traffic in many tunnels, with frequent train service, will be worked electrically, in which cases the problem will be greatly simplified. Several tunnels on English railways stand in great need of improvement, such, for instance, as that under Sydenham Hill, on the London, Chatham and Dover, and that at Sevenoaks, on the South Eastern Railway.

The Author desires to call particular attention to the need which exists in many tunnels during construction of a sufficient and even bountiful supply of fresh air to the workmen. With it they work with far greater comfort and vigour; without it the work progresses far less rapidly, at greater cost to both the company and the contractor, and with lasting injury to the men.

As regards work under compressed air, attention has been on several occasions directed at the Institution to the still greater need of ample air beyond the air-lock,[1] to secure immunity from the various symptoms ordinarily developed by compressed-air work.

Ventilation of Buildings.

The ventilation of buildings usually falls within the province of architects, but the matter has not hitherto been efficiently dealt with in practice, and is of such importance that the Author desires to submit a few remarks upon it. The present age of sanitary progress may be dated from the serious illness of H.R.H. the Prince of Wales, contracted in 1871. Many thousands of lives have since been saved by the improvements in drainage which have resulted from the study given to that question; and it is much to be desired that similar attention should now be paid to the kindred subject of pure air and ventilation, so that much-needed remedies may be applied to public buildings and to private dwellings.

To allow sewer-gas to enter a house is now an indictable offence, and the owner of premises who fails to take steps to prevent it soon finds himself before the magistrate. Legislative measures ought to be taken to prevent any public building, hall, church or house from being used, unless a sufficient quantity of pure fresh

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 69 *et seq.*, and vol. cxxx. p. 82 *et seq.*

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air is introduced with regularity. The importance of keeping houses clean, streets swept and sewers flushed, is admitted—all with the object of maintaining the air in a pure condition; and after millions have been spent with this aim in view, air is allowed to become absolutely foul and putrid for want of proper ventilation. Air which has passed through the human lungs has been well designated "air-sewage." It is highly poisonous, and is charged with impure matter. It is then breathed, re-breathed, and breathed again to the injury of all present, and with the result of the serious illness and the death of some.

The condition of public assembly-rooms cries loudly for amelioration. "Let anyone gifted with the ordinary sense of smell, or who knows what fresh air means, enter almost any of the assemblies of public gathering," or the committee rooms of the Houses of Parliament, "after they have been occupied, and let him describe the atmosphere he will meet on entering. It is charged with air-sewage of the vilest quality, the imperfectly removed emanations from hundreds, if not thousands of human bodies, and the microscope shows that the air is highly charged with tuberculous and other dust."[1] Coughs, colds, sore throats, bronchitis, neuralgia, headaches, dyspepsia, and many other maladies are, in many cases, directly attributable to vitiated air; and as a recent writer says, in reply to an objection that open windows allow smuts to enter, "Smuts may be bad, but they are as white as snow compared with impure air."[2]

The condition of the air in houses often results in the rooms becoming dangerous to the health of their occupants. It has been stated by an eminent authority on consumption—Dr. Ransome, F.R.S.—that seventy thousand deaths occur annually in Great Britain from tuberculous diseases, nearly all of which could be avoided were the subject of fresh air both understood and acted upon by the community. Were such a loss of life to occur in battle or by shipwreck people would stand aghast; but this vast multitude are allowed to drop into their graves with hardly a protest or an effort to save them. Were proper precautions taken, these diseases would soon become as rare as the formerly prevailing disease of leprosy. The French require in many of their hospitals 50 cubic feet of fresh air per minute to be supplied to every patient. The

[1] Dr. A. Ransome, F.R.S., "Consumption a Filth Disease." *Medical Chronicle*, December, 1897.

[2] "School Architecture and Hygiene; for the use of School Trustees in Ontario," by J. G. Hodgins, M.A., LL.D., printed for the Education Department, Toronto, 1886.

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Author considers that if 20 cubic feet per minute, which, however, is a low standard, can be secured for each person, the air will be maintained in a sufficiently pure condition for ordinary purposes. Allowance must also be made for any gas-lights in a room. Each ordinary burner consuming 5 cubic feet of gas per hour vitiates the air nearly to the same extent as would five persons, the rule being that each cubic foot of gas burned is equivalent to one person.

The late Dr. Thomas Carnelly, in his report[1] on "The Air of Schools," gives the following Table:—

Method of Heating.	Number of Rooms Examined.	Cubic Space per Person.	CO_2 in Volumes per 10,000.	Micro-Organisms per Litre of Air.
1. Mechanical ventilation	32	160	12·3	18·5
2. Hot pipes and natural ventilation .	43	176	16·3	78·0
3. Open fires and natural ventilation .	84	145	19·2	158·0

This conclusively points to the great advantage of mechanical ventilation.

Carnelly, Haldane and Anderson suggest that 13 volumes of carbonic acid in 10,000 should be regarded as the maximum allowable impurity in school air; and, in a Paper[2] published by the Royal Society on the "Air of Sewers," it is stated that this air has been found to be in a very much better condition than that of naturally ventilated schools, and to contain a much smaller number of micro-organisms than any class of house. The following Table illustrates this:—

Place.	Temperature.	Volumes of CO_2 in 10,000.	Volumes of Oxygen to Oxidize the Organic Matter in 1,000,000 Volumes of Air.	Micro-Organisms per Litre of Air.
	°F.			
In sewers	54·0	7·5	7·2	8·9
Outside air at same time	49·0	3·7	2·2	15·9
In houses—				
One-roomed	55·0	11·2	15·7	60·0
Two-roomed	53·5	9·9	10·1	46·0
Four-roomed and upwards . .	54·5	7·7	4·5	9·0
In schools—				
Naturally ventilated	55·6	18·6	16·2	152·0
Mechanically ventilated . . .	62·0	12·3	10·1	16·5

[1] Proceedings of the Royal Society, vol. xlii. p. 501.
[2] The Journal of Pathology and Bacteriology, November, 1893.

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To give a few particular instances, the first building naturally referred to is the Institution of Civil Engineers, and the Author thinks a debt of gratitude is owed to its architect, Mr. Charles Barry, for the general comfort enjoyed within its walls. It is sometimes thronged with dense crowds of visitors, and yet the air is fairly fresh and free from draught, and is suitably warmed. Were all other buildings as efficiently provided for, there would be no need for this part of the Paper. By means of electrically-driven fans fresh air, warmed as required, is driven into the Theatre, Library, and other principal rooms, through air-ducts, and the foul air is removed from the upper part of the rooms. The design comprises a supply of 420,000 cubic feet per hour to the Theatre alone by the plenum-fan, the volume and disposition of the currents being determined by anemometer observations.

The Houses of Parliament may next be mentioned. These buildings were erected in 1836 by the late Sir Charles Barry, and when it is remembered that this was anterior to the railway mania, and that they were designed for the requirements of 60 years ago, it is not surprising that they are unsuited to the necessities of the close of the nineteenth century. For the work which then had to be transacted in the committee-rooms, they were doubtless of ample capacity, and the ventilation arrangements were evidently the subject of much thought and consideration; but unfortunately they have not been extended concurrently with the growth of public and private business in Parliament, a matter of considerable difficulty where the buildings are so restricted in size. The vitiated air is extracted by furnaces in the roof, the fresh air being filtered through cotton wool, cooled or warmed as required, and pumped into the chambers by fans and machinery. So far so good, but this having been done, much of the good is undone, and the air is admitted through open matting on the floors on which are wiped the feet of those who come from the muddy, or, it may be, dusty streets of Westminster. Need it be wondered at that occasionally there are epidemics of influenza and other maladies amongst Honourable Members of Parliament? In addition to this grave state of affairs, the quantity of air admitted is wholly insufficient, the condition of the lobbies, the division lobbies, and the committee-rooms being most objectionable and dangerous. Cases of blood-poisoning, believed to have been contracted in these rooms, have come under the notice of the Author; and on behalf of the lawyers, parliamentary agents, engineers and other witnesses occupied in the committee-rooms,

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the Author would desire to appeal to the authorities to ameliorate the condition of affairs. It may be difficult and costly to completely remodel the Houses of Parliament, but there is no difficulty in providing at once quick-running and silent electric fans in connection with every room. These would extract the vitiated air, and the fresh air could be admitted in proper situations—certainly not through the floor. This ought to be done before the ensuing session, for the present condition of affairs prevents the business of Parliament and Parliamentary Committees from being properly carried on.

Exeter Hall formed the subject of investigation some time ago. The building is provided with a very fine extracting-cowl situated on the roof; it weighs 2 tons and revolves on a turn-table, and so accurately is it mounted that it can be turned by the little finger. It possesses considerable extracting power, but not enough to secure comfort to a packed audience. The inlets are wholly insufficient, consequently the windows have to be opened in a manner which produces dangerous draughts. On one particular occasion, when every portion of the room was occupied, the audience required 62,000 cubic feet of air per minute, whereas only 11,000 cubic feet were being extracted from the room. Since then improvements have been made, but there is need for still further amelioration of the prevailing conditions.

The Chapel of Harrow School received attention, it having come to the knowledge of the Author that boys occasionally fainted there during Sunday services. On these occasions the chapel is closely packed; most of the windows, being devoted to stained glass, were then hermetically sealed, and almost the only inlets for fresh air were air-bricks in the walls, the extractor in the roof being about 2 feet in diameter, with a gas-ring burner. The condition of the air was appalling. Since the time of the Author's visit some of the windows have been made to open, though with what result he is unaware.

In the case of a church in North Wales visited, having a nave 70 feet in height, there were neither inlets nor outlets, the large capacity of the building being relied upon to provide sufficient air. Consequently it was never changed except when the doors were opened. The air, warmed by pipes and by the congregation, ascended into the high-vaulted and cold roof, where it lost its heat, and fell as a shower of cold foul air on the heads of those present, who again breathed it and sent it on another round.

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This was undoubtedly one of the draughtiest and worst-ventilated churches that the Author has ever entered.

The use of the anemometer for testing the ventilation of buildings seems, with a few exceptions, almost unknown, and is very seldom used. The Author commends it to consideration, for the employment of this instrument would soon reveal the objectionable state of affairs in many buildings.

The Victoria Hospital at Glasgow, and the Royal General Hospital at Birmingham, are ventilated on the plenum system, which so far seems to have proved satisfactory.

In the case of all large buildings three main points have to be considered: (1) The area of floor to be provided for each person; (2) The cubic capacity of the room required for each occupant; and (3) The number of cubic feet of air per minute which must be brought in, and then extracted, for each individual. Nos. 1 and 2 will depend upon the objects to which the room is devoted, whether a ward of a hospital, or a school, or a place of public assembly; and there are numerous text-books on hygiene which will afford sufficient guidance in such cases. As to No. 3 there is great diversity of opinion, but no great harm will occur to an audience occupying the room for a comparatively short time, if 20 cubic feet of air per minute are provided. The United States Book on School Architecture gives a practical application to its remarks on this subject as follows:—

"The amount of fresh air which is allowed to hospital patients is about 2,500 cubic feet each per hour. Criminals in French prisons have to content themselves with 1,500 cubic feet per hour. Assuming that we care two-thirds as much for the health of our children as we do for that of our thieves and murderers, we will make them an allowance of 1,000 cubic feet each per hour, or about 16 cubic feet per minute. Forty-eight children will then need an hourly supply of 48,000 cubic feet. Definite provision must therefore be made for withdrawing this quantity of foul air. No matter how many inlets there may be, the fresh air will only enter as fast as the foul escapes, and this can only find an outlet through ducts intended for that purpose, porous walls and crevices serving in cool weather only for inward flow. What, then, must be the size of the shaft to exhaust 48,000 cubic feet per hour? In a shaft 20 feet high, vertical and smooth inside, with a difference in temperature of 20°, the velocity will be about 2½ feet per second, or 9,000 feet per hour; that is, it will carry off 9,000 cubic feet of air per hour for every square foot of its sectional

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area. To convey 48,000 cubic feet, it must have a sectional area of 5½ square feet." [1]

The Author does not, in giving the amount of fresh air to be supplied, desire that this should be regarded as by any means absolutely satisfactory, but only an improvement upon the present state of things. He is aware that the standard of purity suggested is low, and ought to be exceeded; but he fears that it might deter many from moving in the matter if a proper and higher standard were to be laid down at first. He also desires to point out that one of the most important points to be aimed at is the proper warming of the fresh air introduced into buildings; if this be not done, the first step that is taken when a cold day occurs is to have all the ventilating arrangement closed. The fact should not be lost sight of that the air in a room may be quite cold and yet very foul; whilst, on the other hand, it may be warm and yet perfectly fresh. To avoid draught, the air should enter through a large number of small orifices, so as to thoroughly diffuse the currents. This is done by gratings, but the effect of these gratings is to very seriously diminish the volume of air passing through, owing to friction of the bars. Careful experiments, made for the Author by Mr. C. A. Rowlandson, M. Inst. C.E. (Appendix), show conclusively that very ample grating area is required to deliver a large volume of air. The same remark applies to extracting-flues. Owing to the small size and the roughness of the surface, the velocity of the upward current is small, and it often results in the quantity of air passing through being much less than is requisite.

The Author is of opinion that no large building can be successfully ventilated without some mechanical force furnished by steam, electricity, falling water or some such agency. Fans can then be worked with assured results, whereas automatic extractors not infrequently become inlets, thus reversing the whole system and pouring cold air on the heads of the audience. As regards the plenum system, whatever its merits and its success may be, means should also be provided by the introduction of open windows to aërate when required the whole building in sections; and these should be so arranged that no corner can be left stagnant or unswept by the purifying current. Nothing can take the place of this free circulation, and to be able to take advantage of this

[1] "School Architecture and Hygiene; for the use of School Trustees in Ontario," by J. G. Hodgins, M.A., LL.D., printed for the Education Department Toronto, 1886.

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in suitable weather is most desirable. The extraction of foul air should be effected at the top of a room or building, so as to utilize the natural tendency of warm air to rise. The inlets of air should be by Tobin or similar tubes some 5 feet above the floor. In the case of one of the American legislatures, the warmed fresh air is allowed to enter on the level and in front of the desks of each member, so that he secures a proper portion of fresh air before it is breathed by his neighbour.

As regards private dwellings, improvement must be sought in the education of the public to the value and merits of fresh air. Many, if not a majority of, persons seem to regard air as a somewhat questionable gift, and look upon night air as absolutely poisonous, to be excluded from their rooms at all cost. The simplest method is to keep the window slightly open at both top and bottom, so as, in fact, to provide an "up-cast" and "down-cast" current. If this be found to be obnoxious, let a window board, 6 inches deep, be placed under the sash; this keeps an opening at the meeting rail, which, in conjunction with the chimney flue, will prevent asphyxiation.

Analyses of vitiated air taken from crowded rooms, showing the injurious condition of affairs, and also the improvement in the quality of the air resulting from mechanical ventilation might have been appended to the Paper; but such information will come with more force from those accustomed to deal with chemical and bacteriological questions.

In conclusion, the Author trusts that the Paper may, by permission of the Council, be a means of arousing attention to its subject, which he feels to be one of the greatest import to the community. In regard to private dwellings it is much needed, whilst in the case of churches, theatres, and other public resorts it is of pressing importance. If attention and interest on the part of an audience are to be maintained under any circumstances, fresh air should be provided without undue admixture of a poison which produces languor and disease.

The Paper is accompanied by sketches from which the Figures in the text have been prepared.

[APPENDIX.

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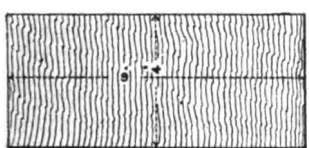
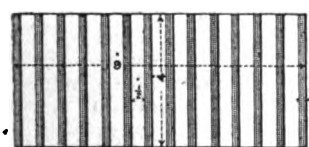
APPENDIXES.

APPENDIX I.

Forced Draught, High Velocity. Measuring-Box fixed in a Scale Door near a 40-foot Guibal Fan running 44 revolutions per minute, with a Water-Gauge at the Fan of 2·5 inches.					Natural Draught, Low Velocity. Measuring-Box fixed in Soot Door at foot of a Cold Chimney 90 feet high, serving a Lancashire Boiler, but no Fire in Boiler at the time. Natural Draught upward. Weather calm.				
Aggregate Area of Airways.	Airway, per cent. of Full Aperture, (I).	Velocity of Air.	Volume of Air.	Volume of Air, per cent. of Volume passed by Full Aperture, (I).	Aggregate Area of Airways.	Airway, per cent. of Full Aperture, (I).	Velocity of Air.	Volume of Air.	Volume of Air per, cent. of Volume passed by Full Aperture, (I).
Sq. Ins.	Per cent.	Ft. per Min.	Cub. Ft. per Min.	Per cent.	Sq. Ins.	Per cent.	Ft. per Min.	Cub. Ft. per Min.	Per cent.
36·0	100	5,400	1,350	100·0	36·0	100	1,100	252·5	100
12·0	33	2,880	720	53·3	12·0	33	275	68·0	27[1]
10·5	30	2,308	577	42·0	10·5	30	213	53·0	21[2]
4·6	13	1,016	254	18·8	4·6	13	61	15·0	6[3]





The shaded portions indicate open airways.

[1] Number of II Grids required to pass as much air as one clear opening 9 inches by 4 inches, like (I); high velocity = 1·38; low velocity = 3·71.

[2] Number of III Grids required to pass as much air as one clear opening 9 inches by 4 inches, like (I); high velocity = 2·34; low velocity = 4·76.

[3] Number of IV air-bricks required to pass as much air as one clear opening 9 inches by 4 inches, like (I); high velocity = 5·3; low velocity = 16·8.

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APPENDIX II.

EXTRACT FROM THE REPORT OF THE ENGINEERS APPOINTED BY THE CONSEIL FÉDÉRAL SUISSE TO EXAMINE THE PROJECT FOR TUNNELLING THE SIMPLON PRESENTED BY THE DIRECTION DES CHEMINS DE FER DU JURA-SIMPLON, OCTOBER, 1893. ("Tunnel du Simplon, Projet de 1893." Berne, 1894.)

During the Construction of the First Tunnel.—Ventilation will be produced by air delivered into gallery II. This air will be cooled according to the conditions of temperature by means of water-sprinklers, and its volume should be 1,760 cubic feet per second for each half of the tunnel. The velocity of the current of air produced will not exceed 20 feet per second in gallery II. All the other workings will be supplied with air from this gallery either directly or by means of water-injectors. Gallery II and the transverse galleries should be provided with double doors (on the principle of the air-lock) in order to maintain the necessary pressure in the most distant parts. In gallery II the space between the doors will depend upon the length of the trains, and in the transverse galleries the doors will be placed at the two ends.

During the Working of one Tunnel with Single Line and Parallel Ventilating Gallery.—The two entrances to tunnel I will be provided with doors and corresponding signals, all the transverse galleries will be open, tunnel I and gallery II will be closed at the end where the fan is working. The plant at the north end and that at the south end will work alternately for definite periods. It will be necessary to deliver through the tunnel, in the direction from north to south, a quantity of air corresponding to a total volume of 2,050 cubic feet per second introduced into the tunnel and the gallery.

During the future Transformation of the Ventilating Gallery into a Second Tunnel parallel to the First.—The two entrances to tunnel I will be provided with doors and corresponding signals. The transverse galleries will be closed; tunnel I and gallery II will be closed from the end at which the fan is working. The plant at the north end will effect the ventilation of the tunnel and the plant at the south end that of the parallel gallery, or *vice versa* as the case may be. The quantity of air for tunnel I will be 1,760 cubic feet per second and the same amount will be supplied for gallery II.

During the Working of the two Tunnels, each having a Single Line.—The two entrances of the two tunnels will be provided with doors and corresponding signals; all the transverse galleries will be closed. From the north end a quantity of air from 1,760 to 2,120 cubic feet per second will be delivered into the east tunnel, and from the south end the same quantity will be delivered into the west tunnel, that is to say, in the direction of the movement of the trains. We estimate that the quantities of air quoted under headings *a*, *b*, *c* and *d* will suffice for ventilation in all cases. The atmosphere in the tunnel will never contain a quantity of noxious gases large enough to exercise an injurious influence upon human beings. This opinion is based upon tests made in the Mersey Tunnel, at Liverpool. The quantity of air delivered into this tunnel per minute is 650,000 cubic feet, or 10,830 cubic feet per second. The number of trains passing through per hour is twenty-four, and the gradient 1 in 30, and even 1 in 27 at certain places. As, however, in the Simplon Tunnel the gradient does not exceed 7 per 1,000 and only four trains will pass through per hour, the quantity of air of 1,760 cubic feet per second will amply suffice. If at any time one of the ventilating plants should be put out of service the

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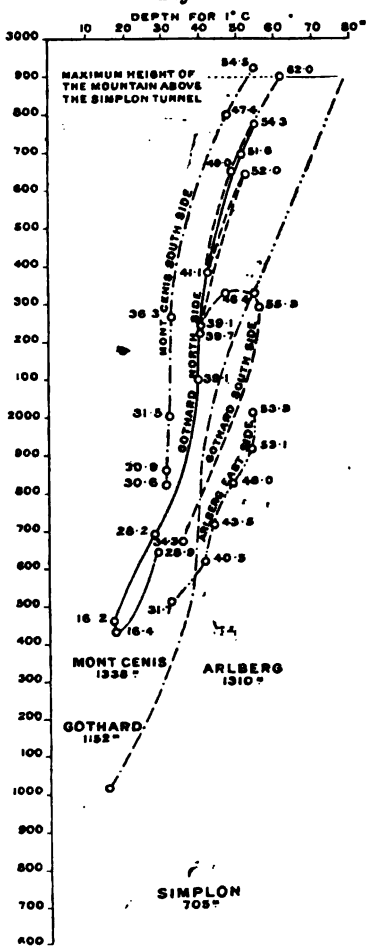
ventilation will be carried on by means of the other plant alone. If, for example, only the plant at the north end can be worked, one of the fans will deliver air into the east tunnel and the other fan will draw air out of the west tunnel. It is of course supposed that the construction of the fans and the arrangement of motive power are such that each fan may be depended upon for twice its ordinary output. In order to make the ventilation certain the doors will not be made of cloth, but will have solid sides perfectly air-tight. For the same reason we recommend the use of fans which have the smallest possible circumferential velocity. After the doors at the ends have been once put in communication with the advance signals and properly arranged, and it has been proved that the working is perfectly satisfactory, the safety of working the trains will not be interfered with by this arrangement. We may observe with regard to this point that the entrance to the Semmering Tunnel (1,560 yards long) upon the Vienna-Trieste line, a similar arrangement has been in use for 39 years in order to prevent the formation of ice in winter, and in spite of the great traffic upon this double-line railway the apparatus has never yet given any trouble.

Fig. 1.



CURVES SHOWING DEPTHS CORRESPONDING TO AN INCREASE IN TEMPERATURE OF 1° C. FOR THE MONT CENIS, GOTHARD AND ARLBERG TUNNELS.

Recently a system of ventilation without the use of doors has been tried in Italy upon the Faenza-Florence and Bologna-Florence lines. This system was designed by Mr. Saccardo, the engineer, and is based upon the principle of the Giffard injector. The air is injected by a fan through an annular opening beyond the mouth of the tunnel, and induces through this opening a considerable quantity of air.

If the tests which are now being made with the Saccardo system on the Pracchia Tunnel (3,000 yards long), on the Bologna-Florence line, give satisfactory results it should be preferred for the Simplon, owing to the simplification it would introduce in the working. We may also remark that this system can be used with doors; but, when the door is shut, it works as an ordinary system of ventilation, such as we have already referred to, whilst during the time that the door is open it will work equally well, and therefore the ventilation will not be interrupted.

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7. What is the maximum velocity considered permissible for a column of air passing through the tunnels and galleries during construction or during subsequent regular working?—It may be taken that a maximum velocity of 20 feet per second is permissible for the column of air passing through the tunnel or galleries during construction or during the subsequent working.

8. Are the proposed means sufficient for cooling the air and the rock inside the workings during the period of construction. Will it be necessary to use similar means during ordinary working of the tunnels?—The proposed means for lowering the temperature of the air and of the rock in the interior of the tunnel during the period of construction are sufficient. In *Fig. 1* are shown, by means of curves, the depths for which the temperature increases 1° C. in the Mont Cenis, the Gothard and the Arlberg Tunnels, so that it might be possible to confirm the temperatures predicted by geologists. This method appears to us specially useful because local influences at different points of observation would lose their importance. If we make the same comparison for the Simplon, on the hypothesis that the form of the Simplon is the same as that of the Gothard, we shall find at the part of the tunnel which is deepest from the surface of the soil the following temperature :—

Approximate thickness of mountain	7,200 feet.
Depth for which the temperature increases 1° C. according to annex *c*	203 „
This gives a temperature of 7,200 : 203 . . .	35·5° C.
Temperature of the soil	1·0° C.
Total	36·5° C.

We cannot, however, absolutely accept this figure for the temperature, as will be seen by the section in annex *d*. The surface of the earth at the two sides of the Simplon Tunnel rises very high, whilst at the Gothard it rises only at one side; for this reason we must increase the estimated figure by, say, 2·5°, as seen by the comparison of the observations made at the Gothard. We therefore consider that the temperature of the rock may be taken as about 39° C. as a maximum. It must be observed that, as the valley is considerably deeper at the Simplon than at the Gothard, the level of the curve showing depths for which the temperature increases by 1° C. ought itself to be lowered in proportion; this, therefore, causes a corresponding decrease in the figures reached gradually at these depths. The curve for the Gothard in relation to the level of the valley of the Simplon (dot and dash) shows this increase. Doubtless it is probable that the temperatures of the rock will not absolutely follow the law given by the curve referred to, but it nevertheless proves to us that the temperature of the rock in the Simplon will be rather lower instead of higher than we have calculated. The hypothesis that the temperature of the rock will not reach a figure which is objectionable is based also upon the observation that the strata come freely to the surface owing to the configuration of the valley, and that the ends of the strata are nowhere covered with a considerable volume of detritus; also that the rocks through which the tunnel passes are not covered with intermediary strata of lower conductivity for heat which could act as an insulating medium and thus maintain the internal heat of the soil. Tests made in our presence at Winterthur have proved to us also that a temperature of air from 40° to 50° C. can easily be lowered to 15° by water-spray at 12° C. under a pressure of 80 lbs. per square inch. The effect of cooling will be still

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more favourable when water at a higher pressure is used, and it may be expected that this process will produce ozone which will render the air richer in oxygen. The abundance of water is such that cooling operations can be carried out on the largest scale: it may therefore be taken for granted that the conditions of the contract will be fulfilled, as they stipulate that the temperature in the workings shall not exceed 25° C. Besides this there are so many cases in which it has been shown that workmen can carry on their labour in a temperature as high as 50° C., that we are convinced that the workmen at the Simplon would be able to bear a temperature not only of 25° C., but even of 32° C., provided that special attention is devoted to sanitary conditions and to relieving the workmen at short intervals. In order to facilitate the cooling of the workings, the radiation from the rock inside the galleries can be hindered by covering the walls with well-jointed planks, or some other insulated covering. On the other hand, during actual working of the tunnel, it may be considered that it will not be necessary to resort to this means for cooling.

At the Gothard, as well as at the Arlberg, it has been found that the temperature is diminished considerably after the opening of the tunnel, as may be seen from the following Table:—

DECREASE OF TEMPERATURE OF THE ROCK AFTER COMPLETION OF THE GOTHARD TUNNEL.

Date of Observation.	Decrease of Temperature at 8,000 yards from North Entrance.			Decrease of Temperature at 7,700 yards from South Entrance.		
	Temperature.	Decrease.		Temperature.	Decrease.	
		Successive.	Total.		Successive.	Total.
	°C.	°	°	°C.	°	°
April and May, 1880	30·46	..	..	30·53	..	..
June, 1882 . . .	23·73	6·73	..	23·39	7·14	..
July, 1885 . . .	22·20	1·53	8·26	23·10	0·29	7·43

THE ARLBERG TUNNEL.

Date of Observation.	Decrease of Temperature at 5,500 yards from the East Entrance.		
	Temperature.	Decrease.	
		Successive.	Total.
	°C.	°	°
September, 1883	18·5	..	..
January, 1885	15·3	3·2	..
„ 1886	14·8	0·5	..
„ 1887	14·7	0·1	..
„ 1894	13·8	0·9	4·7

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Thus the temperature of the Gothard has been lowered 7·43° to 8·26° C., and that of the Arlberg 4·7° C. Natural ventilation only is now used in these two tunnels, and during construction no extraordinary means were employed for ventilation and cooling of the air. At the Simplon, on the contrary, even during the construction, extraordinary quantities of air will be available. Cooling by injection of water promises to furnish specially favourable results. Finally, we may remark that the parallel position of the two excavations for tunnel I and gallery II, or tunnel I and tunnel II and their transverse galleries, will exercise an important influence upon the cooling of the rock. After tunnel I has been constructed, the water-pipes will still be available for use, and it will be possible to find if the method of cooling the walls will afford during the actual working, and maintain advantages sufficiently important to justify (from a financial standpoint) the permanent maintenance of these pipes. Sprinkling of water in the tunnel, during actual use, would serve not only for cooling but also for the absorption of carbonic acid-gas and the production of ozone.

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Discussion.

Mr. W. H. Preece, C.B., President, said that, by the applause with which the members had received the Author's communication, it was almost a work of supererogation on his part to propose a vote of thanks to him for the excellent Paper which had been read. But it was the duty of the Institution when an Author took a good deal of pains with a Paper, as the Author evidently had, that a hearty vote of thanks should be accorded to him. The Author need not fear that he would fail in arousing attention to the subject of his Paper. He had put before the members in an admirably clear way some very novel and interesting facts, and had also introduced matter which was to a certain extent contentious. It was therefore hoped that the Paper would excite an earnest and active discussion. Notwithstanding the remarks which the Author had made with regard to the admirable ventilating arrangements in the theatre of the Institution designed by Mr. Charles Barry, he could assure the Author, and also the members, that a careful analysis which had been made recently showed that the air in the lower part of the theatre at the conclusion of a fairly full meeting contained 6 to 8 parts of carbon dioxide in 10,000, being thus, according to the Author's Table, superior even to air in a sewer! In the upper part of the room, at the level of the lantern-hatch, the impurity was 2½ times greater, but nevertheless was still well within the standard which the Author had laid down of 20 parts in 10,000. It was therefore not wonderful that after a violent discussion in that room the members all went away cheerful because they had been breathing pure air. He endorsed fully and wholly the remarks made about the air of the committee rooms of the House of Commons. He never spent a day in those dungeons without suffering the effects of a severe headache, and if the deputation that had waited that day upon the Chief of the Office of Works submitted among other things Mr. Francis Fox's Paper, and if their arguments had been enforced, as he had no doubt they had been, with true engineering vigour, upon Mr. Akers Douglas, it was to be hoped that before the next session commenced, that at the end of a day of examination in the witness-box the engineers would feel as cheerful as they did when departing from the Institution meetings. Mr. Preece.

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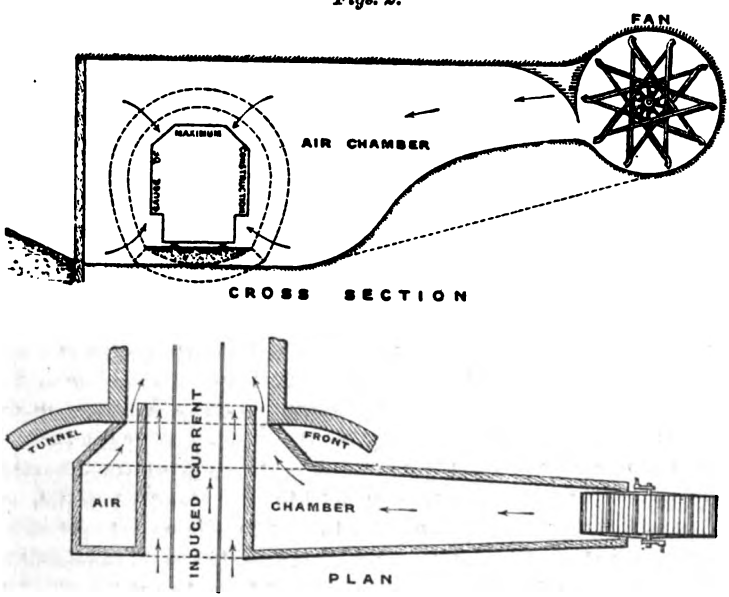
Mr. Fox. Mr. Francis Fox had been reminded by Sir Frederick Bramwell that the first tunnel ventilated by a fan was that which formed the approach to Lime Street Station, Liverpool, which had been efficiently ventilated by the late Mr. Ramsbottom. The Saccardo system of ventilation was illustrated in *Figs. 2*, representing its application to a single-line tunnel. The tunnel was extended for about 15 or 20 feet by a structure either of timber or brickwork, the inside line of which represented the line of maximum construction, and this was allowed to project for about 3 feet into the tunnel. The space between this line and the

Figs. 2.



The Saccardo System of Ventilating Tunnels.

exterior constituted the chamber into which air was blown by means of a fan. Considering that the tunnel was 3,000 yards in length, he had first thought there might be some tendency for the air to return through the open mouth, but nothing of the kind happened. The whole of the air blown by the fan, 164,000 cubic feet per minute, was augmented by the induced current yielding 46,000 cubic feet per minute, making a total of 210,000 cubic feet; and that volume was blown down the gradient against the ascending train, so as to free the driver and men in charge of the train from the products of combustion at the earliest possible moment.

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He ventured to think that was one of the greatest advances that had been made in the ventilation of tunnels within memory. It could be added at a minimum of expense to any tunnel. With regard to the opinions of Sir Benjamin Baker, Mr. Moir, and other gentlemen, on the even greater necessity that existed for purity in compressed air than in air under the ordinary pressure, he desired to add a few words. With air under pressure, on entering the lock, the air was absorbed by the blood, carrying with it any gaseous impurities in its constitution; and, consequently, if it were at all high in carbonic-acid gas the blood received that impurity. In coming out of the compressed air, as was well known, it was of great importance to be locked out slowly. The physiological reason for that, he believed, could be best illustrated by the difference between opening a bottle of soda-water rapidly, by taking the cork straight out, or letting the pressure off slowly at the mouth of the bottle. If it were let off slowly, the gas escaped almost imperceptibly, whereas if the cork were taken out rapidly, the gas was evolved in large bubbles at once. It was well known that blood in the presence of air tended at once to coagulate, and recent investigations of certain cases which had occurred in the deep sinking of cylinders at Newcastle and elsewhere showed that when the pressure was taken off, and the globules of air were formed, the same tendency was for the blood to coagulate. Where deaths had occurred, and post-mortem examinations had been made, the veins and arteries had been found filled with coagulated blood, consequently producing death. If the pressure were allowed to pass away slowly, this risk was reduced; the danger lay in the possibility of the formation of a clot in the system. In the Paper he had referred to the air which had been breathed as air-sewage. Anything which had passed through the human body ought to be treated as excreta and rejected; just as sewage was thrown away into the drains, so air that had passed through the human lungs should be got rid of at the earliest possible moment without allowing it to go through the lungs of someone else. He thought it was as unreasonable to breathe the same air twice, or 12 or 20 times over, as was the case in many places, as it would be to go to the sewers for drinking-water. Mr. Fox.

Dr. J. S. HALDANE was very glad to see the cause of good ventilation so ably and energetically taken up by the Author before the Institution. It was with respect to buildings used for public purposes that it seemed to him there was, in England at least, greatest need for practical reform as regarded ventilation. He Dr. Haldane.

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Dr. Haldane. would lay before the Institution shortly considerations which, self-evident as they might perhaps appear to the members, were only forced upon him by the results of a series of investigations undertaken as part of the work of the Home Office Departmental Committee on Water-gas. In the course of those investigations it was necessary to determine very carefully the rate at which the air of an ordinary bedroom was changed. It would be seen at once that in the case of an accidental gas escape, especially where the gas was highly poisonous, as was the case with water-gas, the danger to the person occupying the bedroom was very great. He took the case of a bedroom because such accidents nearly always occurred at night. The danger to the persons occupying the bedrooms would depend on the rate at which the air was removed from the room by natural ventilation, through the walls and roof, and so on. He had to investigate rooms of different sizes, and one point which came out clearly was that the larger the room, the slower was the rate at which the air was changed. It took for a room 3,000 cubic feet or 4,000 cubic feet in capacity nearly twice as long for the whole of the air to be changed as in the case of a room of 1,000 cubic feet. Following out that line of investigation, it was very clear that the larger the room the slower was the ventilation. Consequently a certain amount of cubic space which had a certain value for respiration purposes in a small room, had not nearly the same value in the case of a large room. In the case of a room of 30,000 cubic feet, 1,000 cubic feet of space had only about one-third the value of the same cubic space in an ordinary small bedroom. The reason was that the cubic capacity of a room, or of any other space, taking the rooms of the same shape, increased as the cube of the diameter; whereas the surface of the room increased only as the square of the diameter. The ventilation, in whatever way it was brought about, depended on the passage of air through the openings in the surface of the room, through the walls and through the roof, and so on; and the consequence was evident, that the larger the room the less value the cubic space. It was possible to calculate the diminution in the value of a certain amount of cubic space for ventilating purposes by simply following the rule that the capacity increased as the cube of the diameter, whereas the surface increased only as the square. The practical outcome of that was that when the rooms were of a certain size, it became almost absolutely necessary to provide mechanical means of ventilation. In public rooms of all kinds, as a general rule, the amount of cubic space allowed per person,

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while the room was occupied, was even less than in ordinary dwelling-rooms, and the amount diminishing on one hand, and the value of that amount diminishing still more rapidly, perhaps, on the other hand, the air was bound to become exceedingly bad in the course of a short time. Dr. Haldane.

Mr. E. W. Moir had discovered in the Hudson and the Blackwall tunnels the real meaning of ventilation, as he had had the misfortune to see a man's veins opened when he was just dying and had helped to squeeze the coagulated blood out of his system. There seemed a great difference of opinion as to what was ample ventilation, and there was a still greater variance in dealing with compressed air. It was stated in the Paper that the French in their hospitals allowed 3,000 cubic feet per man per hour. The Author himself thought that 1,200 cubic feet were sufficient, and he believed his opinion had been confirmed by a Commission on barracks, which reported that such a quantity of air per man per hour would suffice. A man at rest respired about 0·6 to 0·7 cubic foot of carbonic acid per hour, and the air in cities generally contained between 0·3 and 0·4 cubic foot; so that the impurity contained in the air, which would be gauged by the amount of carbonic acid, would be about 1 part in 1,000. That was a much greater degree of purity than was found in many public buildings and other public places in London. In Dr. Andrew Smith's work on "Air and Rain," he found examples of analyses taken in several public places, one of which was the Haymarket Theatre at 11.0 P.M., when there was 0·7 part per 1,000. That was remarkably pure for a theatre. In the Chancery Court Dr. Smith found 2 parts per 1,000, 7 feet from the ground; and he found, in 300 samples taken from the workings in mines, an average of 7·8 parts. In one case, in a heading of a Cornish mine, as many as 25 parts per 1,000 had been found. On the authority of Dr. Haldane, analyses on the Metropolitan Railway had showed 8·9 parts of carbonic acid at Gower Street or Portland Road; and it would take 30 parts per 1,000 by volume to put out a candle in an ordinary heading. He had been in an atmosphere in ordinary tunnels when a candle would not burn, and no visible ill-effect was apparent on the men working in that high percentage. The carbonic acid seemed simply a measure of the impurities, and not in itself seriously detrimental even in such large quantities. When, however, compressed air was dealt with, it was very different. If the working pressure was above 20 lbs. to the square inch, any percentage which rose above 1 to 1¼ part per 1,000 was almost sure to make itself felt on some men, and Mr. Moir.

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Mr. Moir. might be very serious in its results. At the Blackwall Tunnel and at the Hudson Tunnel it was found necessary, in order to keep the air at the right degree of purity—that was, at about 1 to 1½ part per 1,000—to analyse it regularly. The provision of a constant volume per man, as gauged by the revolutions of the engine, was useless, for it was once found that the air was very impure, even when 6,000 to 8,000 cubic feet were being delivered. This case he remembered occurred when the Blackwall tunnel was passing under the old Isle of Dogs sewer. It was, therefore, absolutely necessary to give a varying supply, according to the analyses in compressed-air works, and the limit should be about 1 to 1½ per 1,000. An ample allowance in ordinary works, and a liberal one, he considered to be between 3,000 and 4,000 cubic feet per man, and even less would do at pressures below 30 lbs. per square inch. He was much surprised to find recently that one of his expert divers now at work was quite content with only 250 cubic feet per hour. The only excuse for his being alive at all, he supposed, was that, being a diver, he was naturally a selected man, and his hours were very short under water; consequently it did not do him very much harm. He had examined a diving-bell plant by one of the prominent diving-plant makers, where an allowance of 1,300 feet was given. It would be seen that the figures varied widely. In undertakings where compressed air had to be used the fair and proper allowance had become a very serious question. He had framed a tender recently for a compressed-air work, where, from humanitarian reasons, the amount was fixed very high—namely, at 8,000 cubic feet per man per hour. To compress that air required a great deal of power, and the cost amounted to considerably more than the man's wages who was going to consume it. Whether their competitors had looked much into that or not he did not know, but they were not the lowest, and he thought that may have accounted for it.

Mr. Pownall. Mr. C. A. W. POWNALL remarked that, in the case of the Usui railway in Japan, there was a gradient of 1 in 15, and, therefore, the tunnels were at a very high inclination, resembling chimneys. In a space of 5 miles, there were no less than twenty-six tunnels, the longest of which was 600 yards. The line had been laid out against his reports to the Japanese Government; but although he objected to the system on various other grounds, he confessed that the difficulty likely to arise with ventilation was not present to his mind. But when the locomotives began running, the difficulty with the smoke was found to

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be serious.[1] When the engines were put to work, the difficulty of keeping steam was very great, and the fires were forced to the utmost; consequently, instead of a coal consumption of 32 lbs. per mile, which Mr. Fox assumed, the coal consumption, in trials which he had to conduct for the Government, was no less than 250 lbs. per mile on an average, and in one case it was as much as 268 lbs. The smoke was so thick that it was impossible to see the man standing also on the footplate, and they were all pretty nearly smothered. On the day before the trials began, when the steam gave out and the engine stopped in one of the tunnels, and remained there for 10 minutes, the driver was almost choked, and the natives lay face down on the ballast to breathe. That bore out the Author's remarks in the Paper about what had happened in Italy, when the drivers were almost reduced to insensibility. In the 600-yard tunnel in Japan, there were reverse curves of 16 chains and 13 chains radius, and consequently the smoke had to turn the corner to escape. The speed of the train was only 5 miles an hour, so that the smoke kept pace with it. The tunnel was for a single line, with sectional area of 180 square feet. When the train was in the middle it had passed through $900 \times 180 = 162{,}000$ cubic feet of air, and in running this distance at 250 lbs. of coal per mile 42 lbs. had been burnt. This, at the Author's estimate of 29 cubic feet of poisonous gas per lb., gave 1,218 cubic feet of poisonous gas introduced into the 162,000 feet of air; the ratio of the gas to the air was therefore as 1,218 to 162,000, or as 1 part to 133 parts, whereas the Author's standard of purity of 20 parts in 10,000 was a ratio of 1 to 500; therefore at the Usui the air was nearly four times too foul. Various schemes were proposed for remedying the nuisance and danger, as it undoubtedly was. The Saccardo system, which the Author had described, was not known at that time, and, no doubt, it would be an admirable method, because it would keep the smoke from following and smothering the train and driver. As it was, the very primitive method was adopted of hanging a curtain at the lower entrance of the tunnel, and closing it as soon as the train had passed in. That stopped the draught of air following the train, and enabled the train in some degree to liberate itself as it passed up. It was a very curious experience; he had spent 4 days there trying the engines, and it was not only disagreeable, but positively dangerous to be in such smoke as he had described. In laying out mountain lines, or lines involving

Mr. Pownall.

[1] Minutes of Proceedings Inst. C.E., vol. cxx. p. 48.

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Mr. Pownall. many tunnels, too much attention could not be given to the question of ventilation.

Dr. Armstrong. Dr. H. E. ARMSTRONG thought the blame for defective ventilation lay not so much with the public as with the architects, and in a minor degree with the engineers. There was no doubt that not only were architects generally not sufficiently cognisant of the importance of ventilation, but they had practically no ideas on the subject as to the way in which air could move and should be made to move. He thought that if the Metropolitan Railway were mentioned at all, it should not merely have been said that 86 parts of carbon dioxide per 10,000 had been found in the air; the case should have been dealt with as a whole. With extraordinary skill, Dr. Haldane had managed to find a pocket in which he discovered that quantity; but Dr. Armstrong had made a great many determinations on the line, commencing 15 years ago, when he was engaged by the District Railway Company to work up the matter; and more recently, when he was undertaking a similar examination in connection with the Board of Trade inquiry, and he practically never found so large a proportion as that. He admitted there were occasions and conditions under which large amounts could be found, but it was clear why that was the case, and the implication that such a proportion as that mentioned was in any sense an average one was altogether unjustifiable. The matter had been dealt with so fully in the comprehensive report issued recently by the Committee appointed by the Board of Trade to inquire into the system of ventilation of tunnels on the Metropolitan Railway, that it was not necessary to do more than refer to that report.[1] He ventured to think that in referring to the ventilation of buildings the Author should not have said (p. 8) that it had been stated by Dr. Ransome, F.R.S., that 70,000 deaths occurred annually in Great Britain from tuberculous diseases, nearly all of which could be saved were the subject of fresh air both understood and acted upon by the community. He ventured to challenge that statement. On the occasion of the recent visit of the Sanitary Institute to Birmingham a very remarkable lecture had been given by Dr. Hill, the Vice-Chancellor of Cambridge University, on the subject of milk as one of the great causes of tuberculous disease. Which theory was to be accepted; the theory that it was due to absence of ventilation, or the theory that it was due to milk? He thought at the present day the evidence

[1] Report of the Committee appointed by the Board of Trade to enquire into the System of Ventilation of Tunnels on the Metropolitan Railway.

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showed that comparatively little tuberculous disease arose from defective ventilation. A previous speaker had referred to a point which was of great importance, namely that the carbon dioxide was not in itself harmful, but was merely to be taken as the most convenient measure of the impurity present in air. That was well understood. In the Appendix Report he had mentioned it would be found that Dr. Haldane had called attention to a matter which was of very great importance, namely, to the presence of considerable quantities of carbonic oxide in the tunnel air; in fact, Dr. Haldane ascribed the noxious qualities of the tunnel air to the presence of carbonic oxide. It was known perfectly well that there must be carbonic oxide, as it was known perfectly well that carbonic oxide was always formed as a product of combustion; but he thought it was unfortunate that at the time inquiry was proceeding no word was mentioned with reference to this subject. Had it been so, there would have been an opportunity of considering Dr. Haldane's figures and checking them. He believed that Dr. Haldane was, in the main, right, but he was inclined to think that he had exaggerated the magnitude of the evil; Dr. Haldane went so far as to say that he had found a quantity of carbonic oxide which might be expressed by saying that there was 1 volume of carbonic oxide to 13 volumes of carbon dioxide. Those who knew the proportion of carbon monoxide in gases from stationary boilers knew that was extraordinarily high. He did not know at the time of any work on the subject of locomotive boilers. Had he known earlier, he would certainly have asked the authorities of the Metropolitan Railway to allow him to make a few journeys again on their engines and endeavour to find out what the percentage was. He believed that if it were found possible to reduce very considerably the amount of carbonic oxide in the gases escaping from the locomotives, the difficulty which arose in railway tunnels might very materially be reduced, because there was no doubt that the carbon dioxide would do no harm even if present in much greater proportions than it was ever likely to be. A little smoke, more or less, was not harmful. It was carbonic oxide against which it was most necessary to guard, and he ventured to think that a point which should have been brought out by the Author, and it certainly behoved engineers, who probably could remedy the evil to some extent, to take note of it. With regard to mechanical ventilation as against any other system, he supposed it was agreed that means of that kind were necessary in dealing with tunnels such as had been referred to. But the question of house ventilation was very different, and he

Dr. Armstrong.

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Dr. Armstrong.

could not help thinking that from that point of view the remarks which had fallen from Dr. Haldane might be a little misleading. It was not at all clear what condition his rooms were in. There was no doubt that in days gone by rooms were very fairly and fully ventilated through the brickwork. That was a most efficient, and probably the best form of ventilation which could be obtained, because it was the only way in which air was admitted freely over the whole surface without the production of draughts. That was the view which Pettenkofer, who was the father of all enquiries in such matters, had held very strongly. But dust had come to be regarded as the greater evil, and very frequently the walls of houses were rendered impervious —not absolutely, but much less permeable—either by cementing them, or worse still, covering them with a paper and varnishing it. There was no doubt that that was a method which, although entailing advantages, from the ventilation point of view entailed great disadvantages. After all, the admission of air into ordinary buildings was the question of great importance. There was no great difficulty, as a rule, in getting air out. Everything in an ordinary English house showed that the desire was for air to get in. If the chimneys of any house were tested under which fire was not burning, it would be found that there was a strong down-draught, and the amount of air that came down through the chimneys in that way was proof that the architect had not provided a sufficient inlet of air. A few Tobins distributed about in a room were not sufficient to do the work. There was no doubt that the great problem in household ventilation was that of letting air in and not that of letting air out. With regard to the modes of getting air in, he had noticed that the Author, on the whole, seemed to prefer mechanical means. Unfortunately he had lived for the last dozen years or more under a system in which air was forced in, and anything more pernicious he could not imagine, in London, at all events. It might be satisfactory, perhaps, in the dustless atmosphere of the country, but in the dust-laden air of the metropolis such a system was abominable, and his experience would lead him to prefer in all cases the introduction of air by suction rather than by pressure. That system had the great advantage that the air could be introduced at a very large number of places without producing draughts. He was not sure that when the electric traction system came into general use the public would be so satisfied as they thought they would be. Nothing could be more unpleasant than the air of the City and South London Railway, and yet if it were tested chemically

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it would be found that the amount of impurity was relatively very small, always under 10 parts per 10,000. Dr. Haldane, in his report, had referred to that; and had said there was a distinct musty smell and a feeling of stagnation about the air, although, chemically speaking, it was only slightly impure. It was quite likely that the impurities ejected into the air, especially the sulphurous acid, had the property of disinfecting the tunnel. There was a peculiar and most offensive smell in tunnels which were not subjected to that influence. Probably there was a bacterial growth or a fungoid growth on the surface which gave rise to unpleasant emanations. He thought that was a matter of importance to be taken into account, because it bore on the question of the interior construction of tunnels. He thought the surface of tunnels in the future should be made so smooth that they might either be washed, or scrubbed down, or whitewashed at periodic intervals. If electric traction was to be used, it would be advisable to prepare the tunnel in such a way that at regular intervals it could be disinfected, otherwise people would complain much more of the smells in times to come than they did at the present day. He thought that a great deal of misconception had arisen with regard to the Metropolitan Railway. The Author said that it was only fair to point out that fan ventilation on that railway had never been practically adopted. Dr. Armstrong thought that that sentence ought to be read, "It is only fair to point out that ventilation on that railway has never been allowed to be adopted." If the line was examined it would be found that in those parts where there were considerable openings, it was not so bad, as compared with the standards which had been laid down, as to raise much objection. There was a large amount of evidence which showed that when proper openings were provided it was quite easy to keep down the amount of impurity to a reasonable extent. Those parts of the line which had been so complained of were not in any way provided with openings, and were those in which the provision of openings by the railway company had been prevented by public action. Therefore he did not think it was fair to cast aspersions on the line without fully recognizing the actual facts of the case. He had been struck with a statement of a previous speaker that it had now become absolutely necessary in working under pressure to analyse the air. If engineers and architects had their attention called to the matter in that kind of way by systematic analyses being asked for, probably they would think about it a great deal

Dr. Armstrong.

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Dr. Armstrong. more than they did. A good beginning had obviously been made, and if the discussion led to that practice becoming more general, he thought that important results would be obtained.

Mr. Inglis. Mr. J. C. INGLIS endorsed the opinion of the Author that, "had the civil engineer and the architect applied to all the works under their care, the rules and regulations observed by the mining engineer," there would not have been so much trouble as there was in the present day. At the same time, he thought it was well to sound a warning note that the question of ventilation of tunnels was a matter of degree. He had had to make observations and notice the behaviour of the atmosphere in the ventilation of many tunnels, and he could understand how it was that costly extracting or forcing apparatus were not erected in the first instance. That question ought to be kept in mind in making a general statement. In tunnels, where the ventilation had been provided for on an elaborate scale, it was well known that the provision for ventilation applied for a certain service, and when that service increased it might become altogether inadequate, and damaging criticisms might be made upon it if the original provision for traffic was not kept in view. He was afraid he was one of those individuals who were not able to detect carbon dioxide when walking through a tunnel, although he certainly had sometimes felt a disagreeable effect from doing so. One case which he had in mind was the Severn Tunnel. For traffic up to a certain limit, say trains passing every 20 minutes or even 15 minutes, the ventilation of that tunnel was all that could be desired. In thundery, dull, and damp weather—he mentioned damp weather advisedly—a vast change occurred in the conditions of the tunnel, and these were so great, that, while satisfactory results were obtained under normal conditions, in unsatisfactory conditions it was admitted that the results might be very much improved. The Severn Tunnel was ventilated by means of an exhaust, much in the same way as the Mersey Tunnel. If the traffic in the Severn Tunnel became much more intense than it was at present, it would be difficult to decide what would be the necessary steps to cure it. One of the steps, which he would put forward very tentatively, was found in a suggestion which the Author had made in connection with the Saccardo system. Even in the Mersey Tunnel, which had been described as the most perfectly ventilated tunnel in the world, he should not be surprised if that company was fortunate enough to pay a dividend of 10 per cent., to find that they had to face a different set of ventilating arrangements. From the section, it appeared to him

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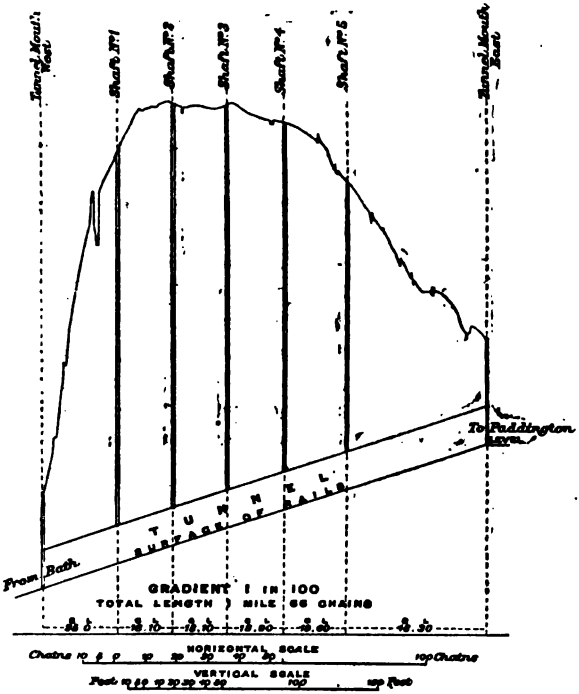
that one of those might be the forcing of air down instead of sucking it up. If there were stations at the end of the tunnel, it would never do to force the foul air into the stations; but in a case like the Severn Tunnel that difficulty did not exist. It was possible that, by forcing a volume of fresh air into the lower part of the tunnel so that the train would run against it and come into the zone of good air towards the bottom, a more rapid means of clearing the tunnel might be obtained than existed at Mr. Inglis.

Fig. 3.



LONGITUDINAL SECTION OF THE BOX TUNNEL, GREAT WESTERN RAILWAY.

present. Experiments had been made in several ways, and he did not think that the passage of trains, at any rate in any dull weather, was advisable at a greater rate than one in 20 minutes. That would give an idea of what the limit of a reasonable provision of ventilators meant in a tunnel like the Severn Tunnel. In another instance, namely, the Box tunnel, *Fig. 3*, which was 1 mile

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Mr. nglis. 66 chains in length with five shafts, part of the difficulty in the ventilation of that tunnel where natural atmospheric influences were depended on was that several of the five shafts acted at times in a manner prejudicial to the efficient ventilation of the tunnel. The tunnel was on a rising gradient of 1 in 100, and the section of the ground rose abruptly at each end. With a westerly breeze, as the tunnel lay east and west, the most advantageous conditions of ventilation held, but when the wind was exceedingly slight at times shafts Nos. 1 and 2 acted as intakes and so diverted the rising or westerly current of air through the tunnel. This had been complained of by the men many times, as delaying the speedy clearing of the tunnel of steam. Again, assuming shafts Nos. 1 and 2 were not acting as down draughts, but were either up or neutral draughts, shaft No. 4 must frequently draw up more strongly than any of the others, and so abstracted the westerly current as well as the steam hanging in the tunnel, and what did not escape through shaft No. 4 found its way to shaft No. 5, with the result that the easternmost 48 chains of the tunnel was left unventilated, and in this length this steam, due to the passage of trains through it, hung to an inconvenient extent at certain times. He had looked through this tunnel from end to end, and it had been perfectly clear; but he had known cases in continuously dull weather when the men not only could hardly do any work for a week, or see 2 yards in front of them, but had to come out to the mouth every hour to get fresh air. Under ordinary conditions the ventilation of the tunnel was perfect. He mentioned those facts to show the extreme variations in the conditions which had to be dealt with in providing sufficient ventilation in tunnels. Another point was the question of the corrosion of rails in tunnels; the Author, however, did not give any idea of what it meant. He believed that the ventilation of railway tunnels was not a matter seriously affecting passengers, drivers or guards of the trains; but that the real pressure came from the permanent-way men who had to live in the tunnel, and from the excessive cost of the maintenance of the permanent way in tunnels by imperfect ventilation. Much to his disappointment he had had to relay a great part of the Box Tunnel after the rails had been in an exceedingly short time; and before such an operation could be undertaken the whole circumstances had to be very carefully examined. From recent examination he had found a maximum corrosion and wear—because rails wore so much more quickly in a tunnel than in the open air. Particulars of the wear of the rails in the Box and

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Severn Tunnels, as compared with rails at either end, were shown in the following statement:— Mr. Inglis.

BOX TUNNEL (1 mile 66 chains in length).

Percentage of Wear per Annum.

	Per cent.	Lbs. per Yard per Annum.
Down line, gradient falling 1 in 100—		
At east mouth	0·439	= 0·377
28 chains from east mouth	1·800	= 1·540
48 „ „ „	2·110	= 1·810
1 mile 8 chains from east mouth	2·880	= 2·480
At west mouth	0·640	= 0·553
Up line, gradient rising 1 in 100—		
At east mouth	0·620	= 0·575
1 mile 8 chains from east mouth	1·500	= 1·380
1 mile 28 chains from east mouth	1·520	= 1·310
At west mouth	0·680	= 0·587

SEVERN TUNNEL (4 miles 28½ chains in length).

Percentage of Wear per Annum.

	Per cent.	Lbs. per Yard per Annum.
Down line, outside and quite clear of tunnel, Bristol end, gradient falling 1 in 100	0·280	= 0·240
Up line, outside and quite clear of tunnel, Newport end, gradient rising 1 in 100	0·440	= 0·390
At Bristol mouth, gradient falling 1 in 100	1·200	= 1·020
33 chains from Bristol mouth, gradient falling 1 in 100	2·160	= 1·860
3 miles 75½ chains from Bristol mouth, gradient rising 1 in 90	1·900	= 1·630
At Newport mouth	0·310	= 0·270
Down and Up line under main-shaft level	3·200	= 2·750

It would be seen that the maximum wear and corrosion together amounted to the extraordinary weight of 2½ lbs. per yard per rail per annum. Such a statement was a very serious one and involved a great expenditure. The wear was found over the whole of the rail, but the top, over which the engine and train passed, wore at a greater rate, he presumed on account of the surface being kept bright and the gases being able to operate on it. But the rails also wore all round. The Great Western Company tried to overcome that difficulty by boxing up the rails. He tried such experiments in the Severn Tunnel, and boxed up the rails so that the ballast approached the surface of the rails within 1 inch or 1½ inch, but it was found that—in the case, at any rate, of the limestone ballast—the cure was almost worse than the disease. The result was that it was found there was a maximum wear of 2½ lbs. and an average wear of from nearly 2 lbs.—just under 2 lbs. per yard per rail per year. The

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Mr. Inglis. average on the open line might be about 0·25 lb. in the same time. All that he had said applied to the Box Tunnel, which would be thought a very well ventilated one. The wear in that tunnel was greater than the wear in the Severn Tunnel, and he presumed the reason was that the ventilation was better in the latter. It was mechanical ventilation, and there was a distinct difference in the rate of wear; not only that, but he believed that it could be shown—the rails had been weighed very closely—that even where the air rushed up, where it was foul, a difference in the rail could be noticed, so delicate was the waste—assuming that there was a considerable amount of moisture. There were parts of the tunnel where the wear of the rails was not different to others, but in all those where it was excessive it was very moist, either from water falling or from the peculiar moist state of the walls hanging up a foggy atmosphere in some way which always kept the tunnel damp. He mentioned those matters to show that there was a chemical side to that ventilation question which would, he thought, cause engineers to look very carefully to the provision of ventilation in tunnels. His opinion was that it was dangerous to make a general statement, but it was generally believed that sucking air in was better than forcing it in. He had shown at any rate that for tunnels there was a case open to be discussed; that when the traffic was very intense it was quite possible that the question of forcing air in might have to be considered to meet the difficulty. Practically, as he had been reminded, it was the Saccardo system. He was not surprised to hear the observations which the last speaker made about the air in electric railways, after what the Author had said about the cold, foul, second-hand sort of air found in churches. It would be remembered that the Author described that the effect of going to church was to sit down under a cold torrent of air continuously. If the Author was keen enough to notice that in a church, what would he not notice in an electric railway, where the air was used over and over again. He really thought there was a good deal in the point, that the question was the changing of the air apart from keeping it in a pleasant state. As to the ventilation of buildings he had seen and investigated one building some time ago, a Board School, where not only, as far as he could judge from inspection, the conditions were most satisfactory, but where he found that all the masters spoke in the highest terms of the condition of the ventilation. The architect in that case had provided for sucking the air down from a central tower, which had been made

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there partly for effect and partly for that purpose, pushing it into a chamber where in winter there was a heating apparatus and in the summer cold water, and injecting the air into tubes proportionate to the size of the rooms to be dealt with, and bringing the fresh air into the building through a groove or chink at the top of the dado which ran round the rooms. That system, as far as he could make out, was certainly the most simple and the most perfect he had yet noticed. He did not know how much the protection was worth, but there were screens of gauze which were kept moist, and the air was drawn through them. Certainly the account he had and the conditions which he noticed were very satisfactory. Mr. Inglis.

Sir BENJAMIN BAKER observed that Mr. Inglis, as Chief Engineer of the Great Western Railway, had introduced two very important practical points into the discussion. One was the abnormal wear of rails in tunnels, which had been exercising the attention of engineers not only in the Severn Tunnel, but in all the Alpine tunnels, and in every important tunnel throughout the world. The rapidity with which the rails wore out in tunnels, owing to bad ventilation, was extraordinary. In many cases a special section of rail had been introduced. It was not merely the rapid wear, and therefore the increased cost of maintenance, but it was also that for some reason or another, either a mechanical or chemical reason—mechanical in the sense of rusting causing an incipient crack, or chemical for some reason which was not quite clear—there was certainly a much larger percentage of breakages of rails in tunnels than at other parts of a line. That was a very practical point for the consideration of railway engineers. Another point which Mr. Inglis referred to was that in ordinary tunnels—and by ordinary tunnels he included Alpine tunnels, but not such tunnels as the Metropolitan or the City and South London Railway—the public were very little concerned. It was, as Mr. Inglis said, the permanent-way men who were interested in the ventilation of tunnels. If there were good carriages, such as were customary on continental railways, with the windows fairly tight-fitting in order to keep up the temperature in the winter, there was no Alpine tunnel or any other tunnel in the world which was so long that the fresh air locked up in a carriage was not ample to see the passengers through that tunnel, however full of bad air that tunnel might be. He quite agreed with the Author that 1,200 cubic feet per hour was the sort of thing to be aimed at in schools and dwellings, and other places where people had to remain a long time. Even more than that Sir Benjamin Baker.

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Sir Benjamin Baker.

—Mr. Moir had said 3,000 cubic feet—was still more desirable in work under compressed air. But if engineers attempted to give 1,200 cubic feet an hour in all cases, an enormous number of people would be killed. Supposing that were attempted to be done in a railway compartment in which people were travelling, in very cold weather, with the thermometer far below zero, in Russia or on the Canadian Pacific, everybody would be frost-bitten or die of pneumonia. There was no existing means in a railway carriage of heating anything like 1,200 cubic feet per hour in cold weather, and in a country where the temperature fell below zero it was practically impossible. In steamships and still more in sailing vessels doing the North Atlantic passage, there were no means of heating that quantity of air, and to force down 1,200 feet, and restrict the proportion of carbon dioxide to 9 parts in 10,000, would be to freeze passengers to death. Fifteen or twenty years ago the Americans, who were not entirely behind the age at any time, were investigating that question of ventilation on railways, and they thought if they wanted to look for impure air, requiring improvement in the interests of the general public, they would not look into tunnels, but into the railway carriages. They found that by no appliance of heating which existed on the American lines could they venture in winter to put in more than about 300 cubic feet an hour per passenger; and that was about the best they could hope to do, and it meant about 24 parts per 10,000 of carbon dioxide. He should be very sorry to make an official estimate of what the proportion would be found to be, if the coming Christmas happened to be a cold one, in a crowded third-class compartment in a train going to Scotland, where the train ran every 2 hours without stopping and the windows were all closed, and, if there happened to be any sleet and snow, almost every crevice was frozen up. There would be at least eight people in the compartment, and about 47 cubic feet of air per passenger locked up in that compartment, and the door would not be opened for 2 hours, and he thought he might venture to say that the windows would not be opened either. Supposing that even the amount of air that leaked in during those 2 hours through the frozen-up crevices would supply the passengers with sufficient fresh air for $\frac{3}{4}$ hour out of the 2 hours, that would leave $1\frac{1}{4}$ hour to consume the air which was locked up in that compartment, that was, 47 cubic feet per individual, and that would give 29 cubic feet per hour instead of 1,200 cubic feet, and 210 parts of carbonic dioxide per 10,000 at the usual rate of production, though probably considerably less with the people in a sleepy condition.

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Sir Benjamin Baker.

The passengers would not suffer such an amount of inconvenience from bad air as would induce them to open the windows and expose themselves to the cold; they preferred to put up with 29 cubic feet per hour instead of 1,200 cubic feet and keep warm. It might be said that it was impossible to exist that period of time on 29 cubic feet per hour, that the passenger could not do it, and would probably be half-suffocated. But that was settled by experiments for another purpose. In order to see what quantity of heat was given out by the human body, Dr. Marcet and other gentlemen, last year, experimented by shutting themselves up for an hour in an air-tight box of that exact capacity, namely, 29 cubic feet. They gave all sorts of results as to the quantity of ice which the heat of their bodies melted; but with regard to the foulness of the air, the only remark they condescended to make was that they did not feel any inconvenience—and they were medical gentlemen. But they did analyse the air, and they found that there were 150 parts of carbonic-acid gas in 10,000. The Author very properly said that 1,200 cubic feet a minute was the amount which ought to be aimed at. Assuming that the normal quantity of carbon dioxide was 4 parts in 10,000, taking also 0·6 cubic foot per hour as the amount given out per individual per hour, 1,200 cubic feet per hour would mean a pollution of about 9 parts in 10,000. The experiments cited showed 150 parts in 10,000, and as the temperature was not rising—because the object of the experiment was to see how much heat was given out by the body in an hour—there was no inconvenience felt. Those experiments he should say, taking the normal conditions of a crowded train going to Scotland without a stop for two hours, in cold weather, when the windows were fairly fastened up, fairly indicated what was the sort of air that people were travelling in. They would have about 29 cubic feet per hour, and as they were not exposed to that poisonous atmosphere for any great length of time, they preferred it to the draught and probably rightly so. The 1,200 cubic feet was absolutely impossible in many cases which engineers had to deal with; but the heating and ventilation of railway carriages required consideration, and something should be done. It must not be supposed, from the remarks he had made, that he differed in any way from the general conclusions of the Author, that the aim of engineers and architects should be to get as much circulation of air as was reasonably possible. But they could not accept any hard and fast rule that there must be 1,200 cubic feet or 300 cubic feet or 30 feet. All the circum-

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Sir Benjamin Baker.

stances of the case would have to be taken into account, and their own opinion as engineers obtained, as to what could be done in the particular circumstances that had to be dealt with.

Mr. Statham.

Mr. H. H. STATHAM had heard in the course of the discussion that the want of ventilation in buildings was owing to architects knowing and caring nothing about it, which proved to him that engineers knew very little about architects. He had read the latter part of the Paper very carefully, and he quite agreed with it, and considered its recommendations wise, but he could not say that they were new to him. He could say that a very great deal of trouble was taken in the ventilation of public buildings nowadays, with perhaps two exceptions—churches and theatres. Churches were not ventilated because it was thought irreligious; and theatres were not ventilated because they were generally built by a speculative syndicate, of which the architect was a member, and the object was to get them up as quickly as possible, and spend as little money as possible. With regard to public buildings, they were separated from private buildings by the fact that they were occupied by an exceptional quantity of people. He was glad to see in the Paper what he had been urging for years, that the only way to efficiently ventilate a public building was by mechanical means. He considered that the driving of the air in, on what was called the plenum system, was on the whole the best. He should like to answer one or two of the objections made to it. It was only in the previous week that he had made a careful examination of the new hospital at Birmingham, which was on the plenum system. With regard to the objection that the dust was driven in, that could be prevented. The air was forced in through jute-fibre screens which were kept automatically wetted once in each quarter of an hour. The gentleman who acted as conductor to the party put his hand to the back of the screens and drew it out black; that was where the dirt stopped. With regard to the question of where air should enter, at the Birmingham Hospital the air was driven upwards from the foot of the windows, a glass screen about 18 inches high being placed to give it an upward direction. The air then circulated through the room and was drawn out at the bottom. He confessed he used to be more in favour of extracting it at the top, but if the air was admitted at the foot there was a great liability to draughts. The theatre of the Institution, as had been remarked, was a very well ventilated room, and there was no feeling of want of air, but he had had a very distinct feeling that evening that the air came to his legs first, and he thought it

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was better to admit it at a higher level. As to the disagreeableness of living in a plenum, he questioned one of the nurses who had been in the Birmingham ward more than a year, and she said she never felt any inconvenience from it. He was told that the patients sometimes complained of draughts when the window-blind was hanging down above a ventilator, and saw the blind moving, but the manager said he pulled the blind up, and they did not then feel the draught. With regard to the screening of the air, on one occasion he was informed by more than one witness that when there was a very thick fog in Birmingham, there was not the slightest particle of fog within the hospital walls. In private buildings a totally different condition of things was met with, and it was there he thought that the public were in fault. He did not think it was possible to contemplate the expenditure on mechanical ventilation for private houses, and he hardly thought it was necessary under ordinary circumstances, but the public had such a great horror of open windows, and that was really the cause of the unhealthy conditions of many houses. His own rule had always been to have the windows open in the breakfast-room in summer and winter—to come down to open windows, and close them, in the winter, during breakfast. The windows were open when the rooms were not being used, and by that system there was always plenty of fresh air in the room. He did not think artificial ventilation was necessary in a private room, unless a ball or dinner-party was being given, when a large number of people were suddenly collected in a room where, perhaps, three or four people had been accustomed to sit. That was a totally different set of circumstances, and he was sure that many of the members must have felt at dinner-parties how exceedingly deficient the room was in fresh air. His suggestion would be that in private houses there should be special provision for such occasions. It would not be necessary, perhaps, to use it on ordinary occasions, but when the room was filled with people a special supply of air could be turned on. That appeared to him to be a provision which was very much required. Mr. Statham.

Sir Douglas Galton, K.C.B., found himself more in accordance with Dr. Armstrong's remarks upon the question of the purity of air than with those of his old colleague, Dr. Haldane; but he would rather pass from that subject to the question of the ventilation of buildings. He entirely agreed with the view that in a building which was occupied for a short time at uncertain intervals, it was most desirable that the ventilation should be assisted by mechanical means, either by the plenum or some other system; Sir Douglas Galton.

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Sir Douglas Galton.

and as instances of this he would mention churches, possibly elementary schools, and large public halls where there were very large assemblies at uncertain times. But wherever a building was occupied permanently with definite conditions, as for instance, in a hospital, and in the English climate, where the conditions of the atmosphere, very often, were such that windows might be opened generally for a considerable time, he would say that it was far better to trust to the ventilation of Nature—natural ventilation—than to the artificial pumping in of air. He would mention one point in connection with that. During that part of the year when the windows could be opened, when the air was of such a temperature as it was during the greater part of the year in England, it would be found that if the windows were opened, at least fifteen to twenty times as much fresh air would be admitted into the ward per patient as could be obtained if the air was pumped in, as in the Birmingham Hospital. If, by means of pumping, 3,000 or 5,000 or 7,000 cubic feet of air were given to each patient, by means of open windows as a rule at least fifteen times as much air could be given, and that was certainly much more beneficial to the patients. Moreover, whatever volume per cubic foot of space was admitted to the wards, a similar volume must be admitted to the ward offices, corridors and staircases, necessarily at a considerable cost. He had visited the Victoria Hospital at Glasgow soon after it was established, in the company of Mr. Key, who had advised the adoption of the very able system of ventilation there. They went through the wards, and then he went out with the matron, or head nurse, into the Nursing Sisters Home which was attached to the hospital. He said to the matron, "Why do you not, if you speak so highly of the system of forcing the air into these wards as being so very desirable, adopt it in your own nursing homes?" And she replied, "We find the open windows so very much more refreshing." Of course, for three months in the winter, in the time perhaps of heavy fogs, pumping in the air through a screen might be found more advisable, but the cost was very much greater. He believed, on the whole, hospitals would do better to adopt the open-window system and fresh air derived from that cause.

Sir John Wolfe Barry.

Sir JOHN WOLFE BARRY noticed that the Author stated that the amount of carbon dioxide on the Metropolitan Railway was very high, reaching sometimes as much as 86 parts per 10,000. That particular proportion might possibly have been discovered at some part of the Metropolitan Railway, but he wished to enter

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a caveat at that being supposed to be anything approaching the general condition of the Metropolitan Railway, which was more accurately described by Dr. Armstrong. It was well known that the condition of the underground tunnels in London varied very much from a variety of circumstances, and that particular localities which were under examination were under very different conditions at different times. Those who had to do with the Metropolitan Railway were aware also of how great the influence of the wind was in the production of the conditions of various parts of the line; for instance, if the wind was blowing in one direction—say from the east—the western end of the tunnel was always in a bad condition; and, as Dr. Armstrong had said, it would no doubt be possible, by careful selection, to arrive at a place where 86 parts of carbon dioxide in 10,000 would be found. It was also desirable to realize the conditions under which those samples of air were taken; they were taken with a vacuum bottle which was momentarily opened and a very small quantity captured. The sample was thus taken and the bottle was closed. Under those conditions he viewed with some caution the various samples which were taken as indicating the general conditions of the air on the underground railways. On the other hand, he was not at all prepared to say for one moment that the underground railways were in a desirable state—that, he thought, was thoroughly recognized. He thought it would have been better if the Author, after mentioning the Metropolitan Railway and saying he did not propose to deal with it, as it had been the subject of recent investigation, had either left out all reference to the sample which he thought was an isolated one, of 86 parts in 10,000, or else had given the results of all the sampling which had been performed at various times. The Report of the Board of Trade Committee, however, spoke for itself; it was very carefully drawn, and the only thing those who were interested in the matter had to regret in that Report was that the samples of air which were referred to in that valuable Report were not placed before any of the witnesses who were concerned in the investigation for analysis. In reference to the matter of fan ventilation on the underground railway, it was a pity, he thought, to say that fan ventilation had never been tried, and rather by inference to suggest that the Companies had been lax because of the non-trial of fan ventilation. Fans had been tried, but not, he was ready to admit, on a sufficiently large scale to produce very important results. But the experiments that had been made all pointed to the great difficulty of ventilating the

Sir John Wolfe Barry.

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Sir John Wolfe Barry.

underground railways of London by any system of fan ventilation. The conditions of the railway were so peculiar with the large number of stations which were necessary, and the effect of the wind on tunnels which were so near the surface, and which must of necessity have open stations, was so marked that the difficulties of fan ventilation, although not insuperable, were so great as to render it extremely difficult of adoption, and, as far as his own individual opinion went, he should say that anybody would be embarking on a most difficult enterprise who proposed to ventilate the underground railways of London, with their numerous stations and the necessities of the case, with fans. The question had been before the public at great length with regard to the more natural way of ventilating the underground railways by means of openings in the tunnels, and no one who had had any experience of the subject could doubt that that was the reasonable, proper and scientific way of ventilating the underground railways. The difficulties which were proposed to be met by fan ventilation reminded him very much of the old American story of the man—quoted, he thought, in a novel by Artemus Ward—who had been languishing for fifteen years in a loathsome dungeon without food and raiment, and one day a happy idea struck him, and he opened the window and got out! That really was the question of ventilating underground railways in a nutshell; they were so near the surface, very often not more than 3 feet away from the foot of the arch, that it was really a very simple thing to open the window and let in the air and let out the steam or bad air. What difficulty or what inconvenience had ever been felt from the holes which were made after so great a discussion about 20 years ago? He was bold enough to say none whatever, from the discharge of carbonic oxide, nor in any other way, except the appearance of the condensed steam under certain conditions of the external atmosphere, and the condition of the railway where those holes had been made had been such that it left very little to be desired. He did not mean to say that in that event portion of the railway would not be better with more holes; but, as a matter of fact, the railway between Westminster Bridge and Blackfriars Station was in quite a satisfactory condition, looking to all the reasonable requirements of a metropolitan railway. No one could doubt that the original designers of the underground railways of London if they had then appreciated the vast number of trains that were to be run on those railways, necessitating a proportionate emission of carbonic-acid gas and carbonic oxide, would have made more openings than they did. The whole difficulty

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would have been got rid of if the question of the enormous development of underground traction had been realized at that time. For himself he could not doubt that the reasonable and proper mode of ventilating the underground railways was by making more openings and improving the action of the condensers carried on the locomotives; but he was also bound to say that to some extent the discussion had now become academic, because he hoped and trusted that the experiments which were now about to be set on foot for the two Companies would result in a satisfactory mode of working both those railways by electricity. Therefore what he had said was really more interesting as a matter of history than as any prophecy of what the future would be. The conditions of the Underground Railway when it was worked by electricity would, in his opinion, be most favourable for the development of a large traffic; and he thought as time went on railways of that sort, near the surface, worked by electricity, would be better appreciated and of far greater value than railways constructed in the London clay at 60 feet or 70 feet below the surface of the streets. As to the question of house ventilation, people were too apt to think that the ventilation of buildings could be effected automatically, and some plan had vainly been sought for, which would be self-adjustable and suitable to all conditions of affairs in particular houses. He thought that was a mere idea which could never possibly be realized. The proper system of ventilation of rooms, which were sometimes closely crowded and at others more or less empty, was one which must be made adaptable by human skill and attention to the circumstances of the particular time under consideration, and he saw no hope for automatic ventilation of large buildings. That brought him to the question in which he personally was more interested, namely, the Houses of Parliament. The Houses of Parliament were designed in 1836, and he thought it was a remarkable thing that the architect of the Houses of Parliament so fully recognized at that time the position which he had now ventured to lay down, namely, that the ventilation of a building of that sort could not be automatic. Anybody who had had the opportunity, as he had had, of studying the plans and sections, and the arrangements for ventilating the Houses of Parliament, could not but be very much impressed with the great prevision of the circumstances of the case which was evinced in 1836. The two main chambers of the building, the House of Lords and the House o f Commons, the libraries and the lobbies adjoining the two Houses, were examples of most effective

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Sir John Wolfe Barry.

ventilation, and it was a most remarkable thing that year after year passed, with a Legislature which was not altogether apt to hide its complaints, without a single aspersion upon the ventilation of the principal rooms of the new Palace at Westminster. The principle of the ventilation of the Houses of Parliament was that exhaust fires were to be kept in the Clock Tower and the other towers, and every room as far as he knew —every important room certainly—was furnished with chambers above the ceilings which were placed in connection with the exhaust channels leading to those great fires. He supposed that was practically as good a system of ventilation as was known 60 years ago or at the present moment, and he thought the complaint that could now be made was, that as the demand for more ventilation in the Houses of Parliament had been appreciated in consequence of the great development of private business, the Committee Rooms and other rooms, which he could not help thinking were looked upon by officials as of somewhat less importance than the House of Commons itself, were more or less neglected in not being thoroughly exhausted by means of exhaust channels, and that no additions to the means of producing exhaust had been made since the building was finished. As a matter of fact, it had been found from recent experiments that the exhausting power of the fires in the Houses of Parliament, in the towers and in the shafts, was so small when it reached the Committee Rooms, that practically it was of little or no effect. What he wanted to point out was that that was not the fault of the architect of the Houses of Parliament. The fault had been entirely in not adapting the means which had been placed at the disposal of those in charge of those buildings to the modern circumstances by increasing the draught, either by fans or otherwise, and so utilizing the ducts and channels for the exhaust air as to make it sufficient for the modern demands of the rooms in which many members at one time or another found themselves. Nobody could have possibly foreseen in 1836 the immense demands upon the Committee Rooms which had taken place since the great development of private business. He only wanted to make these few remarks, not as any criticism of the Paper, which he thought was one which well repaid careful consideration, but merely for the purpose of explaining, he might almost say, his position in regard to some of the matters to which reference had been made, and certainly the position of his father, the architect of the Houses of Parliament. He should like to state that the present Commissioner of Works had been good enough at last to realize

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that something ought to be done for the development of ventilation in the Committee Rooms, and he was about to do exactly what might have been done many years ago, viz., to increase the draught by mechanical means, using the original channels for the exhaust air of the Committee Rooms, and turning it out more directly into the open air by means of electrical fans. He thought that those who had to do with private business ought to be very grateful to the present Commissioner of Works for that concession, but he could not help also saying that those were matters which might have been attended to very easily 20 or 30 years ago, and which involved scarcely any structural alteration of the buildings from their original design. Sir John Wolfe Barry.

Mr. ALEXANDER ROSS remarked that in the case of the ventilation of buildings and dwellings foul air must be continually and gradually removed and replaced by pure air, but without draught; while with the ventilation of tunnels, large volumes of air, varying in quantity, must be removed suddenly and at stated times, quickly, and by the easiest means possible, regardless of draught. Therefore, while the object aimed at with regard to two subjects, namely, pure air, was the same, the conditions surrounding them were such that they were practically independent subjects. With regard to dwellings, no doubt it was of the first importance that those who inhabited them and occupied them for many hours at a time should have pure air; but there was this practical difficulty, that even if the best possible means were provided for ventilation, there were certain classes of the community who would immediately destroy them; and it seemed to him that, in facing that difficulty, if ventilation was a national requirement it should be accompanied by inspection and control. That, however, was an excuse which was not valid with regard to public buildings. He thought that the tunnels throughout this country might be classified into:—(1) Tunnels under hills and mountain ranges, generally at the summit level of a railway, although not always; (2) Tunnels under streets; (3) Tunnels under rivers or estuaries of rivers; and (4) Underground tunnels for electric railways. Taking the first class, tunnels under mountains and hills, which were by far the largest number and had the greatest aggregate mileage, he thought it might be taken almost without exception, that those tunnels had been constructed by means of shafts sunk from the surface, by which the excavated material had been removed, and the materials of construction introduced. Those shafts were completed and left afterwards as permanent ventilation shafts. Until within recent years, when Mr. Ross.

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Mr. Ross. the Totley Tunnel of the Dore and Chinley Railway was constructed, which he thought was about 3½ miles in length, the three longest tunnels in this country were those piercing the southern end of the Penine Range, one belonging to the London and North Western at Marsden, one belonging to the Great Central Railway Company at Woodhead, and the summit tunnel of the Lancashire and Yorkshire at Littleborough. Those tunnels were of about the same length, he believed something like 3⅛ miles each. He knew them well and he had never heard any complaint from the public on account of want of ventilation. In fact, he believed that Sir Benjamin Baker put the matter rightly when he said that the amount of air in the carriages themselves was sufficient for the passengers for the few moments that were occupied in passing through some of the longest English tunnels. Again, it had been said that the main motive for ventilation was its necessity for the platelayers. He was bound to say that he had never heard much complaint from the platelayers. He thought that, as a class, platelayers working in tunnels lived as long and were as healthy as those working outside. It had frequently been his duty to walk through tunnels in many parts of the country when the traffic was at its height, and he thought such a promenade through a tunnel was an experiment on a full-size scale. He would try and describe what really did occur in his view. On arriving at the end of a tunnel which he wished to enter, he should first of all get the men to light up their lamps ready for walking through. It was prudent to wait until a train had entered, because it carried the draught with it, and the air-current followed it. The walking party might now enter and follow in pure air. The steam-engine was in front, but proceeded at such a rate as to outstrip its own steam and smoke; its own steam and smoke and the air combined followed, the walking-party coming afterwards. If no fresh condition arose, the party might issue out at the other end in that way. If, however, shortly after they had entered the tunnel, a train arrived and entered the tunnel at the other end, on the other line, the draught of the first train was immediately checked, and eventually a calm ensued, and so on, until the train from the other direction passed, when it would be found that the current had entirely changed, and flowed outwards. If a party entered the tunnel at the other end, their experience would be exactly similar. It seemed to him that what really occurred was, that on a train entering the tunnel simultaneously, or nearly so, at each end of the tunnel, each induced

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an inward draught. That draught gradually decreased as the trains approached each other, and somewhere in the middle of the tunnel the air was being more and more compressed, and expelled through the ventilating shafts, if there were any, until the point of passing occurred, when the air was very much disturbed and stirred up, and the two trains in receding from each other created a fresh draught outwards, and so on. He explained that because, in his view, the trains themselves gave mechanical ventilation. With the second class of tunnels, those under the streets, such as the Metropolitan and the District, he did not intend to deal; but for the reference of Sir John Wolfe Barry, he thought the Author had practically avoided the subject altogether, seeing that it was under consideration, and must be understood to be in very good hands, and that something was going to be done. But even as regarded the Metropolitan, he thought the great inconvenience the public felt was in the trains and on the platforms, owing to the smoke being allowed to issue out of the tunnels into the stations, and, when the doors were opened, getting into the carriages. With regard to the third class of tunnels, those under estuaries and rivers, with the water overlying them, and no possibility of shafts, mechanical ventilation became a necessity, and in the two types of railway in this country, that under the Mersey and that under the Severn, mechanical ventilation was very properly applied. Then as to the fourth class, deep tunnels for electric railways, in that case the trains so nearly fitted the tunnels that he believed the piston-like action of the trains themselves would be sufficient to cause efficient ventilation in those tunnels. Coming now to the practical suggestion made by the Author, of using the Saccardo method, he had some apprehension that if, by means of a fan, air was blown into the tunnel, that air would not naturally follow the walls throughout. He thought that the air and the induced air would, in a very short distance after it entered the tunnel, become involved and become one. Then, if that air was blown against an advancing train, as he understood was intended, the train on meeting it would turn the current and bring it back again. If not, there must be, at any rate, some considerable struggle between the two forces when they met. He did not know exactly when and where and under what conditions the Author recommended that system to be applied, and he had endeavoured to show that for tunnels in this country from 3 miles to 3½ miles in length none was necessary under the

Mr. Ross.

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Mr. Ross. normal conditions, and he thought if a tunnel had a good section, of say 27 feet in width, 20 feet to the soffit of the tunnel above the rail-level, and a clear sectional area above the rails of about 460 square feet, no other aid to ventilation was required other than that given by the trains if sufficient ventilating-shafts were provided. He should be glad to know—as he knew the Author was hopeful that some practical result should accrue from his very valuable communication—when he proposed to apply it, and what, in his opinion, or the opinion of any gentleman present, was the best section and the best conditions of ventilation—the best design for a tunnel with regard to ventilation. There was just one other matter he should like to mention, apart from ventilation. Mr. Inglis had said that in consequence of the foul air of the Box Tunnel the rails lost as much as 2½ lbs. per yard per annum. He was impressed with the amount of wear, and as a very careful record was kept on the Great Northern, he had looked up the subject, and he found that Mr. Inglis was no doubt quite right under very abnormal circumstances. There was one case on the Great Northern in which the wear was 2 lbs. per yard per annum, but that was with a falling gradient and a station not far off, where brake action occurred. There were also two or three cases of 1¾ lb. and some of 1½ lb., but the average wear throughout all the tunnels was 1¼ lb. per yard per annum.

Sir Douglas Fox. Sir DOUGLAS FOX thought it was a very safe axiom for the railway engineer, in dealing with ordinary tunnels at any rate, to defer the decision as to what mode of ventilation should be adopted until the action of the particular tunnel in question had been carefully ascertained under different circumstance of traffic and especially of climate. But when such tunnels as the Mersey or the Severn had to be dealt with, natural ventilation was manifestly insufficient. It required but one day's experience to show the late Sir James Brunlees, his brother and himself, that at any rate in the Mersey Tunnel, the line would be absolutely unworkable, in fact, that no person could endure it, without mechanical ventilation. The very first contractor's engine that passed through the tunnel during the construction caused a denser fog than was even met with in the metropolis. The circumstances in that tunnel were very special. There was a length of a mile between the shafts, which could only be dealt with by ventilation headings, and the atmosphere between those shafts was often very damp and very close. The intention of the system of ventilation was to provide for a rapid extraction of the air from the tunnel. It must be remembered that in the Mersey,

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although it was shorter, there was a much heavier traffic, or at any rate a much more rapid succession of trains than in the Severn Tunnel. In the Mersey Tunnel there was a train each way every 5 minutes, that was a train passing through the tunnel every 2½ minutes. The arrangement of the fans had been already described; it was such as to clear the whole length of the tunnel between the two shafts in under 10 minutes. He agreed that at the present time the results there were not as satisfactory as might be wished, and for two reasons, which were mentioned in the Paper, but which he wished to emphasize, first, that the fans, although they were still there, were not run at their full speed for reasons of economy; and, secondly, he was sorry to say, the coal which had been employed of late years in working the traffic on the Mersey Railway was not at all what it should be. But in spite of that, the effect of mechanical ventilation could be seen. In a length of a whole mile without an opening to the surface, the worst result that was found by experiments made by Dr. Haldane, on behalf of the Board of Trade Committee, a result obtained under very abnormal circumstances, close to an engine which was blowing off at the lowest part of the tunnel, was 26 parts of carbon dioxide per 10,000, against the very much larger proportion, more than three times as much, in some parts of the Metropolitan Railway. Therefore, considering the unsatisfactory way in which the system was now being worked, he thought the arrangements for the ventilation of the Mersey Tunnel were such as would have proved thoroughly satisfactory if they had been carried out as the engineers intended. The Author had modestly omitted to mention, with reference to the Simplon Tunnel, a most interesting report made by a technical commission called in by the Swiss Government, of which the Author himself was a member conjointly with Mr. Wagner, the Chief Engineer of the Austrian railways, and Mr. Colombo, one of the leading Italian engineers. That report dealt with a great many other questions besides ventilation; it dealt with the whole question of the way in which the work of the Simplon Tunnel was to be carried out. But with reference to ventilation itself it made several suggestions. It first dealt with the work of construction, and showed how that could be very readily accomplished by driving two single tunnels, like mining galleries, one in advance of the other, and by using compressed-air machinery for the purpose of helping the ventilation as well as working the drills. It also pointed out, and went very thoroughly into the details of the Saccardo system, and it made

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the suggestion—which was after all the best suggestion for curing the difficulties in London—that the railway when it was finished should be worked by electricity. He mentioned that because he thought that so much of the report as dealt with the ventilation question arising in connection with that very important tunnel the Simplon would form a valuable Appendix to the Paper, if the President saw no objection to its being added.[1] One point that he wished to mention was as to the remarks made by a previous speaker with reference to the electrical tunnels in London. The first time he went into the City and South London Railway, with his late eminent friend and colleague, Mr. Greathead, he was very much surprised and impressed with the bad state of the air. He believed that chemically they would have been told it was all right, but certainly to his sensations it was far from satisfactory, and he was strongly convinced that in order to make the electric railways of London as they ought to be, thoroughly efficient competitors with the omnibuses that were running in the fresh air outside, something must be done to clear the tunnels at certain intervals. He did not see that, with present knowledge as to electrical fans, there ought to be any great difficulty in dealing with the matter. It was well known that in those tunnels there was a considerable period in the day when there was a very light load on the machinery, and he did not think it would be necessary by any means to be constantly drawing the air. What was wanted was that the air should have a thorough change at intervals, so as to take away the stuffiness which arose from the fact that a crowd of people were being passed through a small tube. That could be very well done, in his opinion, by the utilization of electrical fans run when the machinery was less loaded with the traction. Under these circumstances, beyond the cost of the original installation and the small cost of the repairs of the ventilating machinery, he did not think that the working expenses would be appreciably enhanced by what would be an immense improvement in the public appreciation of those most important lines. He thought it would do very much to reduce the pressure of the London traffic in the streets. Turning to the other question, with regard to house ventilation and church ventilation, his own experience had been very discouraging. He had the honour of being one of the oldest directors of what were known as "Waterlow's" Buildings. When Sir Sidney Waterlow first erected

[1] An extract from the report referred to has been added as Appendix II, *ante* p. 16.—Sec. Inst. C.E.

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some of these dwellings, he had a very strong feeling that the English public should be educated to ventilated rooms, and he went to the great expense of having ventilating-shafts up the whole of his buildings, with excellent arrangements in the rooms for the purpose. If those places were visited to-day, it would be found they were all most carefully closed by the people who lived in the rooms. He did not know whether it was a privilege or not, but he had the honour of being a churchwarden for some nine years, and all he could say was that the state of his mind at the end of that period was worse than when he began, as to the question of how to deal, not so much with the ventilation, as with the people who came to church. He had found it was necessary to try and reconcile two impossible sets of people —one set who always said they were in a draught, and another set who complained that they were ready to faint. Therefore he quite sympathized with the architects. Railway engineers had only to deal with those very kindly-natured people that Mr. Ross had been speaking about—the platelayers, who never complained; although they were nearly fainting—still they never complained—and had also to deal with railway passengers who shut their windows and did not know much about it. If the accounts were read of what took place in the Mont Cenis Tunnel, and that tunnel was travelled through in a carriage, it would be realized how true that was. The state of things in the tunnel was dangerous to the men, although passengers passed through and knew nothing about it. A different set of people had to be dealt with from those who lived in houses—the Englishmen's castles—people who did not wish to be interfered with; and also people who attended public meetings, and who had very strong opinions as to what the amount of fresh air ought to be or ought not to be. He did not desire to make light of the question, because he thought it was a very serious one, certainly serious to some of them who—inhabited, he was going to say—at any rate attended the Committee Rooms of the House of Commons and the House of Lords for some months, and who had reason to know it. He was very thankful to hear that steps were going to be taken to improve that condition of things, but he was quite sure that a great deal of the future of ventilation, in connection, at any rate, with large buildings, would be due to the improvements in electricity. He had a very strong belief in the proper application of electrical fans. There could not be a better proof of it than the room in which they were sitting. He was not at all sure, however, that they were perfect even there as to the way in which air was

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Sir Douglas Fox. admitted, but he was quite sure that they were able to draw the air out, and that it was done effectively. He hoped that, with some little improvements in the mode of introduction, the Institution would be able to show people what ventilation was in a room fairly crowded. He thought it would be a great advantage if, in some of the large buildings, a thoroughly good experiment could be tried by the use of electrical fans.

Sir A. R. Binnie. Sir A. R. BINNIE thought it might be interesting to place before the members an instance of a tunnel in which the circumstances of ventilation were in no way complicated with those of combustion. When the Blackwall Tunnel, which had two descending gradients and a level of 1,200 feet under the river, was being designed, it became a very important question to decide how the ventilation in such a tunnel should be carried on, and somewhat elaborate arrangements were provided, in case they became necessary, for the exhaustion of the air. He was happy to say that those arrangements for exhaustion had never become necessary up to the present time. But, in order to endeavour to study the question from a more exact point of view than that of personal observation, at the very earliest period after the work was opened a series of meteorological observations of the air and the water in the river were established on the Middlesex side of the river, and maximum and minimum thermometers were established in the tunnel for the purpose of taking the temperature of the tunnel, as well as daily observations of the velocity of the air passing through the tunnel. He would endeavour to give the general results of the observations, which had now extended over something like 18 months, and were carefully recorded twice a day. It was found that, as compared with the temperature of the air above ground, the average temperature of the air in the tunnel was between 4° and 5° lower; this, however, varied. For instance, in last September, during the very hot weather which was then experienced, it was found that the temperature of the air rose 20° or 22° above that of the tunnel. The temperature of the tunnel was highest in the middle portion under the river, where the temperature was between 2° and 2½° lower than the air above. The temperature of the river water was generally 5° or 6° lower than the temperature of the air above it, so that the temperature of the air in the tunnel was between 9° and 11° lower than the temperature of the water in the river. It was found as a result that, taking the average of the whole 18 months, the velocity of the air in the tunnel ranged from 45 feet to 50 feet per minute; it was sometimes a little less. It fell to about 30 feet in

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dull and humid days and rose sometimes to a considerable breeze; in fact, so much so that those people who rode on the tops of omnibuses complained of it as being exceedingly chilly and likely to cause cold. As to the direction of the air in the tunnel, there were two shafts on the Middlesex side and two on the Kent or southern side of the river.[1] In the case of the up-cast shaft (No. 3), which had a long ventilating column, the up-cast was almost continuous, but in all the other three cases it was exceedingly difficult to lay down any exact rule. The currents of air were exceedingly difficult to study. It would be remembered that the direction of the tunnel was generally north and south, and it only happened that when the wind was blowing either from the north or south that a complete draught through the whole length of the tunnel was obtained. He had endeavoured in a few words to describe the result of the operations, and he hoped at some future time, after a little more study, to be able to lay a few more facts on the subject before the Institution. The Blackwall Tunnel could not vie in length with the large railway tunnels of which the members had heard, but it afforded a large experiment, under somewhat difficult circumstances, where the case was not complicated by the combustion of coal in the tunnel itself. It might lead, in the future, to the elucidation of some points which, he was sure every one must admit, were somewhat confusing under existing circumstances. Sir A. R. Binnie.

Mr. W. R. GALBRAITH remarked, in reference to the necessity of ventilating the deep-level tunnels of underground railways, that he had had 3 or 4 months' experience of the working of the Waterloo and City Railway, the length of which between the openings—there was no opening between Waterloo and the terminal station at the Mansion House—was about 1 mile and 3 furlongs. The result of the working had shown that the air was perfectly pure, and there was no disagreeable smell. When he first went through the tunnel of the City and South London Railway he noticed a damp smell, but that was not found in the Waterloo and City Railway. He did not know the reason, or whether the greater diameter of the tubes, which were 12 feet as against 10 feet, had anything to do with it, but the air was very good indeed in the Waterloo and City Railway, not only during the time the trains were running, but at night when the traffic had ceased. There seemed to be a draught right through the tunnels, a distance of 2,500 yards. If the conditions in the railway continued as at present it would be waste of money Mr. Galbraith.

[1] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 50.

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Mr. Galbraith. to think of introducing fans. He believed that the facts that have given rise to comment were, that on the day the Guards arrived in London from Khartum a great number of people assembled at Waterloo, and after the Guards had marched out of the station there was an immediate rush for the electric train. The trains were supposed to carry about 200 people, but there was such a great crush that 600 people crowded into the train. The result was that for some reason or other there was not sufficient power—electricity was still in an experimental state on the Waterloo and City Railway—and the train stuck in the tunnel. The people confined in the carriages with all the windows shut found that the air became stuffy, as might easily be imagined. He need hardly say that the air even in a London omnibus with sixty people in it, and all the windows shut, would not be very good. There was a great outcry that the air in the Waterloo and City line was very bad; but there was a perfect draught through the tunnels and the passengers had not found any inconvenience whatever. Therefore he thought the Company did well to pause before it thought of introducing fans into the railway. The air was pure, the foul air was driven out by the passage of the trains, and there were no products of combustion to make the air foul. Sir John Wolfe Barry had always been, as far as he had seen, a little adverse to the deep-tunnel railways. His view had been that the Metropolitan construction was the proper mode, near the surface of the streets. He remembered Sir John Wolfe Barry in one discussion instancing Glasgow, where they constructed a railway under Argyle Street somewhat like the Metropolitan Railway, and he rather advocated that in contradistinction to the deep-level tunnels. He (Mr. Galbraith) was quite sure that there would be no more railways made in London of the pattern of the Metropolitan Railway, occupying the surface of the streets, breaking up and interfering with every sewer and every gas- and water-pipe along the route which was traversed. That was out of the question. No railway could be made at the expense which would be entailed by such a construction. With regard to Argyle Street in Glasgow, which was instanced, anybody who saw what Argyle Street was during the construction of the Caledonian Railway there would say that London would not for a moment endure such an interruption of traffic and the whole of the conveniences connected with the streets that took place there. Therefore railways of the old Metropolitan type could be dismissed and consideration given to the deep-level tunnels where sewers were avoided and gas- and water-pipes untouched

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except where the line came to the surface. Sir Benjamin Baker had had some experience of surface construction in the Mansion House subways. The amount of trouble entailed in coming near the surface there for a short distance was fearful, and the expense was beyond anything that could be estimated. Therefore a railway driven along the street and interfering with the sewers and pipes was not to be thought of. Then consideration had to be given to the deep-level tunnels, as to which he did not want to say anything at present. He would like only to say a word about the Metropolitan. He did not believe the Metropolitan Railway would ever be pure until it was worked solely by electricity. He thought the Commission made a great mistake, if he might venture to say so, in that they did not recommend what he believed was the original design of the Metropolitan Railway. The railway was designed as a circle, round which trains were to run in rapid succession, and communication with the outside districts was to be made by means of railways coming up to the circle and passengers interchanging. Until the Metropolitan fell back upon that plan and was worked by electricity, he did not think the complaints about the foul air would ever disappear. What the Metropolitan companies ought to aim at was to restore the Circle to its original intention, work it with a rapid succession of trains, and let passengers interchange at junctions at various points. That plan was in force where the St. John's Wood line came in. There the trains ran up to the circle at Baker Street, and every passenger interchanged. He did not suppose there was a larger interchange at any of the stations of the Metropolitan Railway than in Baker Street, and the passengers interchanged without grumbling. The Circle trains had never increased in number since the railway was opened. They ran a 10-minutes' service now as they had from the beginning. If the Metropolitan Company would work its Circle trains at 2 or 3 minutes apart and let all the trains from the country come up and interchange, as they did at Baker Street, then not only would a better service be obtained on the Metropolitan proper, but a more rapid service would be had into the country, because it was impossible that trains at a distance could all run into the Circle and out at various points. He thought that was the remedy: work the Circle by electricity and all questions of ventilation would disappear, and a far better service obtained on the Circle, and a far better service into the country. That, he believed, was the real future for the Metropolitan and District Railways.

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Mr. Wragge. Mr. E. WRAGGE desired to describe his experience in connection with the St. Clair Tunnel on the Grand Trunk Railway, which connected that portion of the Grand Trunk Railway which was in Canada with Michigan. The tunnel was a tubular, 20 feet in diameter, and 2,000 yards long, and contained a single line. When the line was first opened large ten-wheel engines, weighing 200,000 lbs., were used, which were expected to take the same load up the gradient of 1 in 50 as were taken by smaller engines over the other portion of the line on easier gradients. It was found, however, that in taking those loads the links and pins, which came from nearly every railway in the country, were not all of them of sufficient strength to stand the jerk which came upon them when the gradient changed at the bottom from the level portion to the 1 in 50, and frequently the links broke and the train stopped in the tunnel. In almost every instance when that occurred some train-man, who had been left in the tunnel to look after the portion that was left behind, became insensible, and he believed two of the men had died. The engines did not burn bituminous coal, but anthracite in which there was very little smoke. The heavier trains had to be abandoned entirely, and a smaller train taken through which could go through without any stoppage. A great number of the trains that came through were goods trains, and arrangements were made by which those trains were bunched and ran very closely one after the other. In that way the current of air was kept running in one direction for a long time, and after that no further accidents occurred.

Mr. Fox. Mr. FRANCIS FOX, in reply, referred first to a remark of Mr. Pownall's, who spoke of burning in Japan 268 lbs. of fuel per mile. That was an unprecedented amount, and the condition of the atmosphere must have been terrible. Before trains ventured to enter the Apennine Tunnels, the men in charge of trains had to be clothed in thick woollen garments pulled over their clothes. These were wrapped round and round the neck and over the head, and left nothing except a sort of conning-tower slit. In spite of all those precautions the men sometimes arrived at the top of the tunnels in a state of insensibility, but since the Saccardo system had been installed the air was pure and fresh. He supposed most of the members had heard of the accident which occurred in August 1898 at the Ponte Decimo Tunnel near Genoa. In that case a heavy goods train with three engines was going through the tunnel, when it slipped, and the train came to rest in the tunnel on a steep gradient. All the drivers and firemen were

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rendered insensible, lying on the footplates, and then the train ran back down to the lower end of the tunnel and crashed into a passenger train which was waiting to ascend the gradient, with the result that twelve persons were killed and forty injured. That showed that ventilation was, after all, a most important feature in tunnel work. One or two points in the Paper had been objected to by Dr. Armstrong, who had said, first of all, that the reference to the Metropolitan Railway was somewhat too brief; but Sir John Wolfe Barry had said subsequently that it was much too long. He could not accommodate his statements to everybody; but he wished to refer to Dr. Armstrong's observation that some of the statements in the Paper were sensational, particularly the 70,000 deaths from tuberculosis. He had taken the trouble to look up the matter. He was not a physician, but he knew something about the subject, and had hoped that Dr. Ransome would have been present to reply on this point to Dr. Armstrong. Unfortunately, H.R.H. the Prince of Wales had fixed that day to receive a report on the subject of tuberculosis, and Dr. Ransome was consequently unable to attend the Institution that evening. That showed the importance of the subject. He might say that the number of deaths occurring at the present time from tuberculosis had been reduced below 70,000, the figure stated in the Paper. Those figures were correct 5 years ago, and were taken from the Milroy Lectures, given at the University of Cambridge; but at the present time they were about 60,000. In addition to that, there were in England and Wales about 200,000 cases of tuberculosis, and, including Ireland and Scotland, it was computed that there were 300,000 cases at the present time, each of which had the power of spreading the germs, and about 200 fresh cases occurred daily. The sooner tuberculosis was stamped out the better, and the great cure for it was ventilation and sunshine. Dr. Armstrong had said his statement was sensational because tuberculosis was not due to ventilation, but chiefly due to milk. He ventured to point out that it was notorious that the cow-houses in England were filthy and badly ventilated, and if they were properly ventilated tuberculosis would probably be very largely reduced. Again, his figures were said to be sensational because he referred to 86 parts of carbonic-acid gas in 10,000 being present on the Metropolitan Railway. He had to apologise for having made a mistake. Instead of 86 parts, he ought to have said 89. He wished to take the opportunity of saying that he did not for a moment want to depreciate the Metropolitan Railway. At the time of its inception and construc-

Mr. Fox.

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Mr. Fox. tion it was considered one of the wonders of London. It was carried out with the greatest possible skill by Sir John Fowler and Sir Benjamin Baker; but unfortunately it had not been developed according to the increase of the traffic. That was what he complained about, as also the blow-hole system which had been adopted, and in which he did not believe, although he was sure Sir Benjamin Baker and Sir John Wolfe Barry would forgive him for differing from them. Those two gentlemen were advocates of what had been called "the blow-hole system." That system, to his mind, was radically wrong. The rules of ventilation adopted in mines ought to be applied to tunnel ventilation, and if those principles were applied in the case of the Metropolitan Railway the ventilation might soon be put right. For 10 years he had been an advocate of working the Metropolitan Railway by electricity, and he was requested by the late Deputy Chairman of the Company to investigate the subject, which he did. He felt then, and had been hammering at it ever since, that the proper method of working the Metropolitan Railway was by electric traction. Unfortunately the Company had gone to Parliament during the last session, and had obtained powers for additional blow-holes without allowing any of the witnesses who were adverse to blow-holes to express an opinion. He was prepared to show that proper ventilation could have been supplied on that railway for half the amount which was going to be spent on blow-holes; and the company, by its action, was perpetuating the nuisance of turning the products of combustion, or the vitiated air, even when it was an electric railway, into the street. He thought that railways under streets ought not to be ventilated by blow-holes. He thought Dr. Armstrong had expressed the view that it was simply a single chance pocket of foul air that Dr. Haldane had unfortunately come across, which resulted in the statement made as to 86 parts of carbon dioxide in 10,000. The Author ventured to think that there were a good many of such pockets, as the following figures would show. The figures were in the Blue Book, the Report of the Departmental Committee,[1] and it must be borne in mind that he had laid down that the standard of purity in a tunnel ought to be not more than 20 parts of carbonic-acid gas in 10,000. The following were some of the figures—67, 58, 52, 61, 69, 65, 89, 78, 60, and so on. But he ventured to think that the railway between Baker

[1] Report of the Committee appointed by the Board of Trade to inquire into the System of Ventilation of Tunnels on the Metropolitan Railway. Appendix I.

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Street and King's Cross was one such large pocket. It was stated before the Departmental Committee that the "Mersey Railway, with all its fans, was infinitely worse than the Metropolitan Railway."[1] He knew that statement was incorrect; and he therefore invited the members of the Committee to go down to Liverpool and judge for themselves; take their own samples and analyse them, and give the result.[2] They did so, with the following result—8, 10, 15, 7, 13, 14, 21, 12, 26, 15,[3] giving an average of 13·8 or 14 parts per 10,000, as against an average of purity which was aimed at of 20. He might say, with reference to the highest amounts which were obtained, that the figure 21 was taken at the entrance to the fan drift, where there was the greatest concentration of the products of combustion. The other one, as the members had already heard from Sir Douglas Fox, was taken by the side of the engine on which the members of the Commission were standing. The members of the Commission were taken down on a powerful locomotive engine, which was stopped in the tunnel, under the middle of the river, and they took the sample then and there, which he thought was a trifle hard, and obtained 26 parts; but, including even that sample, the average was only 14. In his evidence Dr. Armstrong could not see anything particularly good about the Mersey ventilation, but after a little heckling by the Committee, in reply to the last question,[4] which was, "In fact, if you could bring the condition of the tunnel between Baker Street and Gower Street into as good a condition as the tunnel of the Mersey Railway, it would be satisfactory?" Dr. Armstrong said, "Yes." The result was that the Mersey Railway, with its steep gradients, its inferior coal, its speed of fans lower than was originally intended, contained rather less than a quarter of the carbonic-acid gas which existed on the Metropolitan Railway. He desired to thank Mr. Inglis for his remarks. The Saccardo system, excellent as it was (and he thought it was the greatest advance that had been made of late years in tunnel ventilation), was not applicable either to the Mersey Railway or to the Metropolitan Railway, but was distinctly applicable to the Pennine Tunnels or the Severn Tunnel. He appreciated Sir Benjamin Baker's observations, and the kindness and courtesy which he had exhibited towards the

Mr. Fox.

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[1] Report of the Committee appointed by the Board of Trade to inquire into the System of Ventilation of Tunnels on the Metropolitan Railway. No. 490.

[2] *Ibid*, Nos. 809, 810.

[3] *Ibid*, Appendix I, p. 120.

[4] *Ibid*, No. 1249.

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Mr. Fox. Paper. He did not quite agree with what he said as to the 5 cubic feet per minute, but he agreed with him as to the question of warming. He would point out that carbonic-acid gas coming from individuals was different from carbonic-acid gas which was being turned out by the locomotive, because in the latter case there was the unconsumed carbon and the carbonic oxide, and also sometimes a very considerable proportion of sulphurous acid, and that aggravated the ventilation very considerably. Whilst Mr. Statham might be correct that engineers knew little about architects, he ventured to point out that architects, with certain notable exceptions, unfortunately knew very little about anemometers, and the sooner they learned that the better. He thought that every architect ought to understand exactly the movements of the currents which were alone indicated by the use of an anemometer. With regard to Sir John Wolfe Barry's observations on the ventilation of the Metropolitan Railway, and his exception to the statement in the Paper that fans had never been used, the Author did not mean to say that they had never been put up; fans had been erected, and very likely they were running to the present day, but they were simply toys. They were turning out about 34,000 cubic feet of air per minute as compared with a fan on the Midland Railway which was turning out 131,000 cubic feet per minute. Five times the quantity ought to be driven if any good was to be done, and until the fans were put up in a proper way, he feared he must adhere to his statement that fan-ventilation had never been properly tried. With regard to blow-holes, he preferred Mr. Harrison Hayter's description of them. That gentleman said they "were inefficient, uncertain, and, in calm weather, the effect was almost nil;"[1] and, as the Author had described in his evidence, it was a "cheap, disagreeable, and ineffectual way of attempting to ventilate a tunnel under streets."[2] He had been led to write the Paper because it would bear on the ventilation of the Committee Rooms of the House of Commons; and if the only result of his Paper was to get fresh air into those Committee Rooms, his labour would not have been in vain.

[1] Report of the Committee appointed by the Board of Trade to inquire into the System of Ventilation of Tunnels on the Metropolitan Railway. No. 1072.

[2] *Ibid*, No. 760.

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Correspondence.

Mr. A. S. E. ACKERMANN noticed that the Author gave a formula for calculating the quantity of air required per minute to ventilate a tunnel, but he thought he should have explained how it had been deduced. If the following method had been adopted, it would be seen that no account had been taken of the air required for the actual combustion of the coal. This amounted to nearly 1·0 per cent. of the whole, and in any case should have been mentioned. In the formation of CO_2 the equations $C+O_2 = CO_2$ $(12 + 2 \times 16 = 44)$ (where the second equation referred to the atomic weights of the elements) showed that 12 lbs. of carbon combined with 32 lbs. of oxygen to form 44 lbs. CO_2, or 1 lb. of carbon gave $\frac{11}{3}$ lbs. of CO_2. At atmospheric pressure and a temperature of say 60° F., about 8·6 feet of CO_2 weighed 1 lb., hence 1 lb. of carbon gave $\frac{11}{3} \times 8{\cdot}6 = 31{\cdot}5$ cubic feet of CO_2. The coal was not all carbon; hence 31·5 cubic feet of CO_2 was not obtained per lb. of coal; but, taking a high percentage of carbon, 29 cubic feet CO_2 was given per lb. of coal. The permissible amount of CO_2 in the tunnel air was taken at $\frac{20}{10{,}000} = \frac{1}{500}$, hence for every cubic foot of CO_2 500 cubic feet of air must be supplied; hence 29×500 cubic feet of air per lb. of coal were required; 32 lbs. of coal were burnt per mile, therefore $29 \times 500 \times 32$ cubic feet of air were required per train-mile. Lastly, if there be a train every $2\frac{1}{2}$ minutes, $\frac{29 \times 500 \times 32}{2\frac{1}{2}}$ cubic feet of air per minute was necessary per mile of tunnel, excluding the air required for the combustion of the coal. From the equation $C+O_2 = CO_2$ it was seen that CO_2 required for its formation its own volume of oxygen; hence 29 cubic feet of oxygen were registered per lb. of coal for combustion. Now 21 per cent. by volume of air was oxygen; hence $\frac{29 \times 100}{21} = 140$ cubic feet of air were required per lb. of coal for its combustion, or $\frac{32 \times 140}{2\frac{1}{2}} = 1{,}794$ cubic feet of air per minute were required in addition to the 185,600 cubic feet per minute given by the above

Mr. Ackermann.

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Mr. Ackermann.

formula. That is nearly 1 per cent. more. The general formula, to include the air necessary for combustion, was :—

$$\frac{C \times 31{\cdot}5P \times l \times n \times 10{,}000}{t \times p} + \frac{31{\cdot}5P \times 100 \times C \times l \times n}{21 \times t}$$

$$= \frac{C{\cdot}P{\cdot}l{\cdot}n}{t}\left(\frac{315{,}000}{p} + 150\right) \text{ cubic feet of air per minute,}$$

where C was the coal burnt per train per mile in lbs.;
P „ the carbon in 1 lb. of coal;
l „ the length of the tunnel in miles;
n „ the number of trains that pass through the tunnel in t minutes;
and p „ the number of parts of CO_2 per 10,000 permitted.

Exhaled air was referred to by the Author as "air-sewage"; but it was not so much the CO_2 in the air-sewage that was obnoxious as the organic matter. Professor Huxley had stated that the poisonous effect of CO_2 had been very much exaggerated, for as much as 15 per cent. to 20 per cent. (*i.e.* 2,000 parts in 10,000) of CO_2 might be contained in air without producing insensibility, if the quantity of oxygen be simultaneously increased. He also stated that there were 33 cubic inches of CO_2 per 100 cubic inches of blood, and even in the brightest arterial blood there was more CO_2 than oxygen. The amount of CO_2 in exhaled air was about 4·5 per cent. by volume. On the other hand, if a cold glass bottle be taken into a hot close room, containing many people, moisture containing the organic matter will condense on it, and if one drop of this moisture be injected into a rabbit it was killed. The number of micro-organisms per litre of air in sewers was given in the Paper as 8·9. This was extremely low, and was partly accounted for by the fact that in sewers the micro-organisms were undisturbed by wind, and when once they settled they did not rise again, owing to the moisture on the internal surface of the sewer. The theatre of the Institution was referred to, and it formed a very convenient example for such reference in order to make various figures, which were constantly mentioned in connection with ventilation, more real. For example, allowing 8 parts of CO_2 per 10,000 as the limit of vitiation (though often stated at 6), there was 1 part per 2,500 in addition to the 1 per 2,500, which was normally present. Each person gave off 0·6 cubic foot of CO_2 per hour; therefore $0{\cdot}6 \times 2{,}500 = 1{,}500$ cubic feet of air per hour per person must be supplied. Taking the seating

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capacity of the theatre at 350, $350 \times 1{,}500 = 525{,}000$ cubic feet per hour should be supplied, as compared with the 420,000 cubic feet that could be. On special occasions, such as the opening meeting, 600 members had been present. Still $\frac{420{,}000}{1{,}500} = 280$ persons, and this no doubt covered most of the meetings. The dimensions were $60 \times 40 \times 27$ feet roughly, = 64,800 cubic feet, which only allowed for 65 persons at the 1,000 cubic feet per person rate (the lowest for hospitals), or 260 at the very low rate of 250 cubic feet per head (the minimum for workshops and factories). Supposing the necessary air were admitted by the whole of one side of the theatre (1,080 square feet), then $\frac{525{,}000}{1{,}080 \times 60 \times 60} = 0{\cdot}132$ foot per second would be the necessary velocity of the air. Now air at 60° F. was barely perceptible when it had a velocity of 2 feet per second, and was only a draught when the velocity was greater than 3 feet per second. At 70° the velocity could be greater. Hence allowing a velocity of 2·1 feet per second, the opening to supply the above quantity of air would have to be 8·2 feet square, *i.e.*, $\frac{1}{78}$ the area of one side of the theatre. If, however, the positions of the inlets were suitably arranged, the velocity of entry could be 5 feet per second. The Royal General Hospital, Birmingham, was mentioned in the Paper. When visiting this hospital some three months ago he had looked down the warm fresh-air inlets (of the children's surgical ward), which discharged upwards just in front of the windows, and there saw a collection of rubbish. In the children's medical ward there was no such collection, the children being too ill to throw the toys over in their gambols, as was the case in the surgical ward. The air, though no doubt suitably warmed and cleaned, certainly lacked freshness. In the Appendix, p. 15, it would add to the usefulness of the Table if, in the case of the natural draught, the temperatures inside and outside the chimney were stated.

Mr. Ackermann.

Mr. J. R. BELL failed to see why the tests used were based on carbonic-acid rather than on gases which are apparently more freely miscible in the air and were undoubtedly more noxious. The trains under the Mersey were calculated to aid the admirably designed artificial ventilation very materially. The grading was ideal and constituted just such a "momentum dip" as the Central London authorities had deliberately adopted. In the first train length out of either station a sharp decline took up the work of haulage on the switchback principle, and it was only after passing

Mr. Bell.

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Mr. Bell. the central outdraught, if then, that the engine began to "rush the bank" and emit any gases. Although the engines were heavy and the fuel indifferent, there was no occasion for surprise at the moderate consumption of coal and the still more moderate emission of noxious gas under such conditions. As to the effect of these upon the ventilation it would perhaps be agreed that the amount of induced air-current, like that of air-resistance, bore a geometrical rather than a simple arithmetical ratio to the speed. In this case the trains accelerated the pre-arranged draught when at their highest speed with the gas-emission at its minimum, and counteracted the ventilation when at their least speed and greatest gas-emission. The ventilation under the Mersey was in popular belief much better than that of the landward section from James Street to Central Station—a matter which the Author could doubtless set at rest by explaining the system there adopted and the results of analysis. That train-induced currents helped the fans to a very appreciable extent at all times seemed not unreasonable, and consorted with the belief that artificial ventilation in mines and tunnels seldom performed all the work, but acted largely as a make-weight to determine which of two outlets the air-currents would adopt. The Author's very neat and simple formula for determining the requisite fan-power omitted to mention the length of tunnel, which presumably was 1 mile. That would seem to show that between 2,000 and 2,500 cubic feet of air had to be changed for each pound of coal burnt in the tunnel, whatever its length. In tunnels with steep continuous gradients like the Mont Cenis, not to mention rack-rail gradients, the consumption of fuel was enormous, but a good deal could hardly be said to be burnt, being merely pulled out of the fire-box by the blast. In reference to the excessive wear and wastage of rails in tunnels, he had not hitherto recognized the importance attached in the Paper to ventilation. Tunnels with fairly level gradients were often ill-drained, and in those with steep gradients the free use of sand under driving wheels was often a serious factor. He believed that, before water was substituted, the sand taken yearly out of the Giovi Tunnel amounted to many wagon-loads. Where instead of sand being removed new ballast was wanted in tunnels it appeared to indicate that the original ballast became yearly more compacted and clogged into a hard inelastic pan. The sole of a tunnel below the ballast acted even more like an anvil than the bed of an open-rock cutting. The rail-joints in tunnels were seldom so well packed as outside, and it was not unusually the case that the rails were either ground up with sand in steep tunnels or hammered to pieces in flat ones.

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Mr. Bell.

There was, he thought, little difference in wastage between the ill-ventilated Cenis and the well-ventilated Box Tunnel. Assuming that the Cenis rails were changed as soon as they had lost 10 per cent. of their original weight, the renewal of 300 tons a year denoted a wastage of 30 tons in some 8¼ miles, say 3·61 tons per mile, or 2·3 lbs. per yard. If the view taken above were corroborated by home experience, it would be found that in, *e.g.*, the Box Tunnel, on a gradient of 1 in 100 there would be more wear on the descending than on the rising road, and this it was understood was the fact. It was not easy to see how ventilation alone could materially affect one road in the same tunnel more than the other. If, as suggested above, compacted ballast affected the matter, the rail-wear would increase with the age of the line. It was perhaps hardly fair to take the Author's suggestion to the effect that the annual cost of renewing 150 tons of rails would go far to equal that of fan-ventilation for Mont Cenis, too seriously. After allowing scrap values it seemed unlikely that the renewals would exceed £1,000 a year, while the ventilation plant suggested would apparently have to deliver quite 1½ million cubic feet a minute through an 8-mile duct. On the Indian frontier steep tunnels descending through the rims of elevated plateaux tended to act not unlike the natural passes which were but notches in those rims, hot air ascending in the heat of the day and cold pouring outwards in a stream at night. Forcing cooled air down hill was seemingly not only the desideratum but the easier operation. There was apparently no great difficulty in bell-mouthing a tunnel portal with the Saccardo system instead of contracting the gangway, but the air used in that method should be cooled and moistened at the intake. The Indian Government had had occasion to study such questions in the interests of the frontier railways. Its most notable work of this class, the Khojak Tunnel, was some 3 miles long, and was originally divided by two shafts into three lengths. From near mid length one end falls $\frac{1}{40}$ and the other $\frac{1}{1000}$, so that between the two shafts there lay, as it were, a pocket of dead air. There the ventilation had been much improved by closing both shafts, and it was not thought necessary to do anything in the direction of artificial ventilation. Another tunnel, which, but for the danger of falling boulders, might be opened out, was drained by side adits some 100 yards apart, but these failed to keep the air on the foot-plate breathable and oblique blow-holes had to be made. This tunnel was half-way up a $\frac{1}{40}$ bank of some miles in length. It was only worked in daylight, and with a full load the uphill

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Mr. Bell. speed was but a walking pace with a consumption of fuel reaching hundredweights per mile. The local coal was exceedingly sulphureous and the line was only worked in daylight, *i.e.*, when the air-flow ran usually uphill. The only troublesome cases in India were tunnels at elevations of 3,000 to 5,000 feet above sea-level. So far the advice tendered to the Government of India as to tunnel ventilation was mainly of a negative character and might be summarized as follows:—"Fan-installations were not yet necessary. Having adopted the vacuum brake, supplying the engine-crews with air compressed outside was infeasible. Breathing-masks fed by pipes with air from the front buffer beam were of little use when the wind was with the train. On new lines tunnels should be flatter than the ruling gradient outside. The roomy engine-and-tender cabs should be closely curtained at sides and back with wetted canvas in tunnel sections. Welsh coal alone should be used on certain sections with troop-traffic." Those, till quite lately, were the leading recommendations. If artificial tunnel-ventilation had no field in India, domestic ventilation was very extensive. In Kurrachee the roof of every native hut had a rough but effective fixed cowl for catching the sea-breeze. Up country in the hot season the punkha was universally used. The primary object of punkhas, as of hand-fans, was to move the air rather than to change it, and the cooling effect was due to moving air evaporating imperceptible perspiration from the hands and faces of those fanned. Buildings occupied by Europeans in the Plains were closed tight against hot winds during 8 hours or 10 hours a day for months together, so that a forced draught, cooled by wetted screens, was useful in every case and absolutely necessary in all public buildings. Experience showed that plenum fans delivering at a little above floor-level were better than exhausters near the ceiling. The latter were very similar to the small electric fans now in common use at home, while the plenum fans, known as Thermantidotes, resembled the fans of the Mersey Railway and varied in diameter between say 4 feet for a private house and perhaps 25 feet for a large suite of railway offices. In the abstract the exhauster was the better appliance, but it failed in practice because it drew in hot air from incidental crevices instead of through the watered "tattie" screens. The plenum fan used more power, but it only supplied what was wanted, which would in England appear to be air properly filtered and either cooled, damped, heated or dried, according to the season. Rarefied air was not in itself found objectionable in India provided

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it were fairly dry. Some of the healthiest hill-stations had a mean barometrical pressure of but 24 inches of mercury. It should be added that in the plains during the hot season no attainable amount of forced draught was regarded as a substitute for the evaporative effect of the punkha. Indeed without the punkha a dry and hot draught produced far less discomfort than if damp and therefore ostensibly cool. Mr. Bell.

Mr. MORGAN W. DAVIES hardly thought it could be satisfactorily proved that 1 cubic foot of carbon dioxide would vitiate 500 cubic feet of air to such an extent as to render it inconvenient; but a mixture of carbon dioxide with other deleterious gases, and especially carbon monoxide, if present in the atmosphere to that extent, would probably have that result. Scheurer Kestner, the eminent Alsatian chemist, in a series of experiments he conducted in 1870, on the gases given off from an ordinary boiler, discovered that where the proportion of carbon dioxide averaged 14 per cent., the proportion of carbon monoxide averaged 0·9 per cent. Schwackhoefer, again, discovered, by burning coal in a calorimeter, that after combustion there resulted from 0·2 to 0·8 per cent. of carbon monoxide. Again, some coals were very sulphurous and emitted fumes of a deleterious nature, especially SO_2. It might therefore be assumed that in the atmosphere of a tunnel, when it had been vitiated by the fumes of an ordinary locomotive engine, there were gases present other than CO_2 in larger or smaller volumes, otherwise the proportion of air to render it innocuous need not be so great as 500 to 1. Applying the Author's deductions to the ventilation of the Simplon Tunnel, and assuming the consumption of coal to be 30 lbs. to 40 lbs., say a mean of 35 lbs. per train-mile, and the time occupied in going through the tunnel 40 minutes, the volume of air required per minute would be Mr. Davies.

$$\frac{35 \text{ lbs.} \times 29 \text{ cubic feet} \times 500 \times 12{\cdot}25 \text{ miles}}{40 \text{ minutes}}$$

$$= 155{,}420 \text{ cubic feet, say } 156{,}000 \text{ cubic feet.}$$

Calculating the sectional area of the tunnel at 250 square feet, the velocity of the current per minute would be 624 feet, or about 7 miles per hour.

If P = ventilating pressure in lbs. per square foot.

R = surface exposed to friction = length × perimeter = length × 60 feet.

V = velocity of current in feet per minute.

K = coefficient of friction for velocity of 1 foot in a minute, which for railway tunnels may be taken at 0·00000000228.

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Mr. Davies. Then $P \times \text{area} = K R V^2$ and $P = \frac{K R V^2}{\text{area}}$,

$$P = \frac{0{\cdot}00000000228 \times 60 \times 64{,}680 \times 624^2}{250}$$

= 13·75 lbs., or dividing by 5·2 lbs. the weight of a superficial foot of water 1 inch deep = 2·6 inches of water-gauge. These conditions, both in regard to volume of air in circulation and the water-gauge pressure, were frequently found in the ventilation of an ordinary colliery, so that there would be no difficulty in passing through the tunnel an adequate supply of fresh air on the basis of the Author's deductions, which would certainly be sufficient for all purposes. Having regard to the best system adaptable for the ventilation of long tunnels where a shaft at, or near mid length was impracticable, the Saccardo system undoubtedly offered many advantages over any other system that had so far been applied, inasmuch as the bell-mouth arrangement of the fan drift through which the propelled air entered the tunnel admitted of a more uniform distribution of the inflow air, and with less shock than would be obtainable by any other system of in-blowing ventilator; whereas, on the other hand, any arrangement of exhausting ventilator would necessitate the provision of a door at the outflow end of the tunnel. Such door might, it was true, be made without difficulty to work automatically, but it would involve the introduction of mechanical appliances for opening and shutting it, which, if possible, it would be well to avoid.

Mr. Dolby. Mr. E. R. DOLBY observed that carbonic-acid gas was not the only source of impurity to be considered, and although 1,200 cubic feet of air per person might be sufficient in the case of hospitals, 3,000 cubic feet of fresh air per bed per hour should be aimed at. Ventilation could not be considered alone, but must be dealt with at the same time as the heating, and the standard to be aimed at had been well expressed as that of the condition of the air "upon a hill-side on a bright spring morning." So long as the temperature of the external air was at or about 60° F., no heating would be needed and ventilation could be effected by open windows; but if the temperature were lower outside, then heating would be required. Air colder than the desired temperature of the room should not be permitted to enter, and, if possible, such air should be clean; if the external air were not sufficiently clean, then it was desirable to use mechanical means to render it clean, and in that case mechanical ventilation, by means of a fan, became essential, as the resistance offered to the current by the cleaning apparatus

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could not be overcome by natural draught. In Great Britain it was usual to use either hot water or steam for heating purposes. He considered that each radiator used in a hospital ward should be fixed in a case provided with adjustable openings, so designed that on first heating the ward the air should be caused to circulate through the case and no external air be admitted, and that after the temperature had risen to 60° F., the external air should be admitted as required. If the inlet for the external air were at floor-level, then if the outlets were at ceiling-level there was always a danger in the still air of the wards for a current to be formed direct from inlet to outlet, leaving a large part of the air of the ward stagnant; he considered two outlets were desirable, one at ceiling-level to the upcast flue, and one at floor-level to the same flue, and special valves should be used so that both outlets could never be open at the same time. If open fireplaces were used as an auxiliary means of heating, then these would act as outlets at floor-level and the top outlets might be closed. In public schools in the United States external air was drawn by flue suction into a tiled basement chamber containing a heating apparatus and thence passed up special flues to the rooms. Each room had a special flue direct from the basement chamber. The air, heated to 90° or 100° F., entered the room through a large grid or grids at about 3 feet above floor-level, and the opening of the flue was regulated by a valve. The heated air rose to the ceiling and passed out by a number of openings at floor-level, thence below the boards—thus heating the floor—and through a special downcast flue to a foul-air chamber in the basement, thence through the ranges of latrines and up the large main ventilating shaft. All excreta were perfectly dried (no water-closets were used) and it was only necessary to pour about half a gallon of petroleum on to the dried mass, after which it could be lighted and burnt away. In England Drs. Drysdale and Hayward had given the subject of heating and ventilation of private houses very careful attention, and each had built a house for himself ventilated upon the system alluded to below. The success was so great that one of the members of the family, who for years had been obliged to winter in the south of France, was able to remain in England. The system consisted in using the ordinary kitchen flue as the means of heating a main ventilating-shaft, which caused a suction upon the air in the building. External air was drawn into a basement chamber and, heated by steam or hot-water radiators, it then passed up flues to the rooms. In each room the air was delivered at 65° F. through the cornice and fell through the atmosphere, which was warmer

Mr. Dolby.

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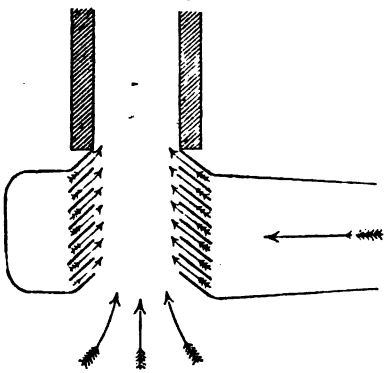
Mr. Dolby. than this owing to respiration of the occupants. The heated air passed out through outlets in the cornice at the opposite side to the inlets, thence to a foul-air chamber at the top of the house, down a main flue to the basement-level, and up the main ventilating-shaft. He had found it very difficult to satisfactorily study the course of the slow and feeble currents set up in most buildings by ventilation; it was possible to do so in certain cases by the use of gardeners' smoke-cones, but he believed the method of experiment with models so strongly recommended by Sir Benjamin Baker was decidedly the best.

Mr. Druitt Halpin. Mr. DRUITT HALPIN considered Mr. Saccardo's arrangement for ventilating tunnels mechanically a very useful one, but he thought a much better efficiency could be produced by a modification of the apparatus, making it more suitable for the large volumes and low pressures of air with which it had to deal. Instead of admitting the air from the fan through one opening only, the efficiency might be very greatly increased by making a petticoat arrangement similar to the one occasionally used in locomotives as shown in *Fig. 4*, care should be taken to have the main entrance well bell-mouthed and formed by easy curves. With regard to the purification of air for use inside buildings, there were four main conditions to be attended to particularly if the air was to be used by persons suffering from consumption: (1) the air should be perfectly free from all mechanical impurities, which experience had already shown could be effected by filtration through cotton wool; (2) the question of temperature, which obviously could be easily dealt with; (3) the hygrometric condition of the atmosphere, and this could probably best be dealt with by the beautiful process described by Mr. Nelson,[1] in which, by a suitable reduction of temperature, all the water contained in the air was frozen out of it, the water being deposited, and any required degree of humidity could then be produced by spraying distilled water into the air; this system of moistening would be absolutely under control and was

Fig. 4.



[1] Minutes of Proceedings Inst. C.E., vol. cxxix. p. 25.

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similar to the course pursued in producing Bessemer metal, where the whole of the carbon was completely removed from the iron and a certain definite amount is subsequently added. The fourth process was the removal of all micro-organisms from the air, and this could be done at the same time as the first part of the third process, while the refrigeration was being carried out, as it was now ascertained that very severe dry cold was absolutely inimical to such forms of life. An apparatus similar to an economizer behind a stationary boiler might be used, having vertical pipes from which the snow could be removed by scrapers acting continuously. Mr. Druitt Halpin.

Mr. MERVYN O'GORMAN remarked that two palliatives for the evils of bad ventilation, among which a risk of consumption undoubtedly figured, were: (1) the filtration and moistening of the air; (2) its proper admission. If moistening were omitted, the air movement incidental to good ventilation produced an evaporation from the body which resulted in a feeling of chill and a parching of the mucous membrane of the nose and throat well known in cold weather, when the body provided both warmth and moisture to the expirated air. If filtration were neglected there was admitted with the large quantity of air now deemed necessary an amount of dust which could only be realized by examination of an efficient filter after a week's run. Ventilation-shafts were useless unless they be made large and accessible for cleansing, and unless they were supplied with air properly filtered, warmed and moistened. The dust, cold and discomfort introduced by some ventilation shafts, as well as their eventual evil odour, easily explain the religious fervour with which such openings were often sealed by those who had to breathe the air supplied, and it was their opinion that was alone worth having. The only way all the entering air could be warmed, filtered and moistened, was on a plenum system. In railway carriages as in rooms, the more thorough the extraction of air the greater the inward leakage through dusty chinks and the worse the draughts. On long runs, instead of 3,000 cubic feet per hour, a passenger had 30 cubic feet, which he preferred to the only alternative of a draught and dirt from the locomotive. Many engineers spent as large a fraction of their lives in trains as others did in Committee Rooms of the House of Commons, and it would before long become important for the railway companies to improve on the present state of their carriages. A simple impulsion fan cheaply served this object. The admitted air could be steam-heated from the exhaust with no greater expense than the heating at present entailed, but the air should not rise from the floor where, unfortunately, people still expectorated. From ex- Mr. O'Gorman

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Mr. O'Gorman. periments he had recently made it seemed that the air-supply to a railway carriage could be warmed with a compact electrical apparatus measuring $1\frac{3}{5}$ square foot by $\frac{1}{2}$ inch thick. Fifty-six feet of platinoid wire zigzagged across a frame 1 foot square had a resistance of 4 ohms, and at 100 volts carried 25 amperes. With a 12-inch fan behind this, delivering about 1,000 cubic feet of air a minute into a room containing 1,500 cubic feet, he found that in 15 minutes the temperature in the room was raised from 8° C. to 12° C., at a cost for current $2\frac{1}{2}d.$, and in the course of that $\frac{1}{4}$ hour 15,000 cubic feet of air had been delivered into the room. If a train were one long Pullman and this supply were kept up, the traveller would be in comfort; not a speck of dust would enter even when doors and windows were opened. The cost to the company for current would be $9d.$ per hour; exhaust steam might be substituted, the cost of the heat properly administered was very small. Micro-organisms were numerous almost in direct proportion as the air was dusty. The monetary significance of dust in daily life was measured by the labour expended in London households, say £2,000,000 per annum, allowing one-tenth of a housemaid's time for dusting to each ten of the population, and even without smoke prevention, this expenditure might be halved by the use of filters and fans. Comfortable breathing required a hygrometric state measured by 3° to 9° difference between the wet and dry bulbs; this might be obtained by a pulverized spray, a wet screen, or a water-trough placed after the heater in the air-way. These also intercepted fog particles, which were vehicles of dirt; indeed it was held by some that fog was more easily removed than other impurities in air owing to this attraction for water. Where the air-velocity was low, a water-spray itself would efficiently wash the air without the spray being carried over mechanically, but this method was expensive because of the large ducts required for the low velocity (say 4 feet by 4 feet 6 inches for this room). It had the advantage, however, of affording little resistance to the passage of air and little expense for filter renewals. If air were drawn through the pores of a fabric or cotton wool, or made to brush past a hairy surface edgewise, trouble arose from the increase of resistance with an increased efficiency of filter. To avoid this a large filter-area was required—thus with a 5-foot fan this room required 400 square feet of filter. If so large an area was not available it became necessary also to introduce exhaust fans (which might be noisy) on the roof, or to increase the speed of the main-supply fan to give the required air-pressure, thus entailing a disproportionate energy consumption

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owing to air-churning. A method which obtained the advantages and diminished the drawbacks of water and cloth was a Key filter of vertical jute strings kept constantly moist and periodically flushed. To diminish the resistance a large area should be employed, say twenty times the fan area. This filter required cleaning. With a cotton-wool filter, such as was used at the House of Commons, after a short period of use the incoming air came into close contact with the deposited dirt on the outer layers of the filter. This dirt being dry was dangerous. He alluded more particularly to the risk of consumption from dust infected by the dry sputum of consumptives. He thought Professor Huxley was one of the first to point out this risk of dry, as distinct from wet particles, and deduce from it and other evidence that the belief in hereditary consumption was erroneous. This risk had come to be admitted by many medical men who might not agree with his deduction. A system which combined the advantages (if any) of cotton wool with those of the water spray, and added to them the efficiency of charcoal as a deodorizing and filtering agent, was the Blackman screen. In a modification specified by his partner, the charcoal or coke screen was constituted of rectangular baskets of portable size, and so arranged that the screen, which was 10 inches deep, was made up of two layers. This allowed the baskets on the intake side to be removed one by one and their foul contents burned under the boiler or radiator. The coke must be kept damp with trickling water to cool, or damp the air, or washed in time of fog. The chief drawbacks to a coke filter were its weight and size (say twenty times the fan area); the absorption of ammonia and other odours was an advantage not to be overlooked. Washing the screen with a hose and leaving the coke permanently undisturbed through a year or two was tolerated by the inventors, though he could not help doubting the wisdom of this course. During a record fog, without a word of warning, he had visited a Bermondsey laundry to examine the linen which was drying in air filtered by this means. There was no water allowable on this filter, but he was bound to admit that the linen was admirably white and speckless. There was a prejudice in favour of withdrawing vitiated air from the top of a room, but when the problem of admission was considered, this view must in many cases be modified. To admit at the floor-level, as in the House of Commons and other places where ventilation had received much attention, was to foul once more the air which had been purified. There were similar objections to admitting air at any level lower than people's heads, for there were inevitable emanations from all living beings,

Mr. O'Gorman.

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Mr. O'Gorman. and dust was easily stirred by the feet into the fresh-air current. Air admitted at the level of people's heads must be directed not horizontally nor downwards, but towards the ceiling. This plan appeared good and was sometimes adopted. There would be leakage if the outlet be in the ceiling, for air unutilized would pass away. This was avoided at Huddersfield Infirmary by outlets at the floor-level; there was no leakage, and the draught, if any, was entirely under the beds. Another method of admission which had been tried, and which on examination showed the utmost promise, consisted of admitting air at the top of the room, through a sheet of uniform texture having the full area of the roof of the chamber. Such a sheet must be capable of being washed (or cleaned by dry process) at long intervals, and was adaptable to large or small rooms. It would have the same effect as deflector-plates in the air-admission holes in the roof of shattering the column of air, which would otherwise descend unbroken on the heads of inmates. The filtered air would pass through the sheet with a low velocity owing to the large area, and for the same cause with little friction. The good air would meet the bad in its ascent, dilute it and drive it out, not only through the apertures provided 1 foot above the floor, but through all natural chinks or open windows to the exclusion of fog and dust. Since the function of the sheet was not to filter, but merely to spread the down draught uniformly, the fabric might be fairly coarse, so that increase of friction need not be considered. It was probable that a prejudice would arise against this arrangement, yet it might, without unsightliness, be adopted in all meeting places (unless indeed the Colisseum were unsightly or the ancient amphitheatres). Silks and tapestries, or prints of any shade of colouring or design, might for this purpose be introduced.

Mr. Rutter. Mr. HENRY THORNTON RUTTER agreed that mechanical ventilation properly applied to the Metropolitan Railway would overcome in a large measure the present cause of complaints. If shafts were taken between the stations, and fans of large diameter running at a low speed were provided, using the stations as the intake of fresh air, the result required would be obtained; at present, owing to varying temperatures of the air inside the tunnel and that of the outside atmosphere, the blow-holes now provided sometimes acted as intakes of fresh air, thereby flooding the station with fumes and *vice versa*, irrespective of the movement of the air caused by the passing of the trains. As regarded the ventilation of buildings, even now many architects thought they had only to cut a hole through to the outside air to

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obtain ventilation; and it was the simple principle of the necessity of not only supplying means for the escape of the vitiated air, but also providing inlets for fresh air without causing draughts that seemed so difficult for them to learn. These requirements led to the conclusion that the plenum system was the most reliable, as, properly applied, by these means the temperature of the air in the various spaces to be ventilated could be adjusted without interfering with the volume of air supplied, whereas in most buildings, where "natural ventilation" was in vogue, the volume of the air supplied was usually capable of being altered. As regarded the quantity of fresh warmed air necessary to be provided, 800 to 2,000 cubic feet per hour per child for schools, according to the class of children attending, 2,500 to 3,500 cubic feet per hour per patient for hospitals and asylums, and 500 to 1,000 cubic feet per hour per person for assembly halls, &c., had given excellent results in his own observations; and, provided the air was introduced sufficiently warmed into the rooms, it could be sent with a velocity as high as 7 feet per second without a draught, though 5 feet per second was the usual velocity adopted. As to the position of inlets and outlets, the fresh warmed air in winter and well-washed and cooled in summer should be introduced about 8 feet 6 inches above floor, and outlets provided at the floor-level for winter, and at ceiling-level for summer use, and so arranged that it was impossible to alter the volume of air either in the fresh-air trunks or vitiated-air outlets, and also that all air-trunks of whatever description could be easily cleaned, as when Tobin or similar tubes were used they were usually so full of dust and debris that they vitiated the air before entering the room. Mr. Rutter.

Mr. A. SCHRAFL, of Lucerne, stated that in the autumn the St. Gothard Tunnel was traversed daily by ten fast through trains, eight omnibus trains, sixteen regular and twenty-seven optional goods trains, in all sixty-one. The first passed through in 15 minutes, the omnibus trains in 22 minutes, and the goods trains in 28 minutes. The use of briquettes was confined to the locomotives of fast through trains, all the others burnt coal. At the centre of the tunnel the minimum temperature of the year varied between 58° and 62°, and the maximum temperature between 72·5° and 74°. It was not so much the combustion of the briquettes as the rapid succession of trains, combined with the momentary equilibrium of barometric pressure between the ends of the tunnel, which caused the accumulation of thick smoke, and the shutting in of the noxious gases in intolerable quantity. The passengers Mr. Schrafl.

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Mr. Schrafl. and the personnel of the engines and trains were, however, not so much affected as those engaged upon the repair of the tunnel and the surface men. It would be impossible to construct air-shafts. During the course of 1898 the installation had been undertaken at the north end of plant upon the Saccardo system. The works consisted essentially of two ventilators, 4·9 metres in exterior diameter, with an annular air-chamber in the interior of the tunnel, all the passages for the junction being in masonry. The apparatus would at first be driven by a steam-engine of 450 HP. With such arrangements it was proposed to drive into the tunnel 126 cubic metres of fresh air per second, and to produce in it a current of 3 metres per second in the direction of north to south, when the natural current in that direction, or *vice versâ*, did not move at that or a greater speed. When this result was once obtained, not only could the survey and the repair of the permanent way and the masonry of the tunnel be carried out in pure air, but a considerable diminution of the wear of the metallic parts of the structure was expected; it was now six times as great as on the open sections of the line. It was presumed also that the ventilation would reduce the time during which the products of combustion would remain in contact with the line, that it would absorb the vapour of water, and that it would prevent in a considerable measure the deposit of soot upon the walls of the tunnel; all advantages which would diminish the formation of rust and so permit of considerable economy upon the cost of maintenance being effected. A trial of the apparatus had been made on the 16th March, 1899, with good results. The atmosphere of the tunnel was formerly in almost complete equilibrium, or there prevailed a feeble current of air in the direction of south to north. The artificial ventilation had produced, in the direction of north to south, a current with a speed of between 3 metres and 2·8 metres per second; so that the repair of the permanent way between 12th and 13th kilometres from the north entrance could be carried out under excellent conditions, while formerly it was necessary to entirely suspend the work. At this point of the tunnel, a momentary stoppage and re-starting of the fans could be perfectly felt. Enquiry was to be proceeded with as to the exact speed of the fans and the driving-power necessary under varying atmospheric conditions, as well as the speed of the current of air at different points in the tunnel.

Mr. Schönheyder. Mr. W. SCHÖNHEYDER thought that in most cases the best manner of warming and ventilating buildings where warm air only was employed for the dual purpose, was that in which the fresh

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warmed air was admitted near the ceiling and the waste air was withdrawn at the floor-level. The air which was admitted to warm an apartment must necessarily be at a higher temperature than that which it already contained, and it must therefore at once rise to the ceiling, where it ranged itself nearly horizontally on the top of the existing cooler air. The new air was again displaced downwards by a further fresh supply of warmed air and so on continuously, whereby the whole of the air in the room was caused to descend in approximately horizontal layers, the new air thus searching and refreshing every corner of the room, and was ultimately withdrawn through apertures in the floor, or by suitable outlets in the walls close to the floor; the circulation of the air being caused either by warm upcast shafts, or by the plenum system. Where very large quantities of gas were burnt the ventilation must be considerably augmented compared to what would ordinarily be required, as stated in the Paper, or separate outlets near the ceiling must be provided. Further, for excessively large areas, or for unusually large window surfaces, specially contrived arrangements were needed. Generally, however, and for moderate-sized rooms, he considered the down-flow mode to be the best, as it gave uniformity of temperature with absence of draughts. Having warmed and ventilated several private houses, rooms and offices with entire success he had experience of the system, the ordinary chimney serving as an upcast shaft, sometimes assisted (especially in mild weather) by a small fire. In a range of offices recently fitted, where chimneys had not been provided, he made an upcast-shaft in each room by inserting a rectangular galvanized tube, reaching through the roof and provided with a windguard as well as a wire screen for birds, &c., and terminating about 3 inches from the floor-level. A small gas-jet was provided inside, and near the base of each tube, to assist the ventilation in comparatively mild weather. In one of these rooms 22 feet by 12 feet 6 inches by 10 feet high, he found one day when the inside temperature was 62° and the outside temperature 52°, or only 10° difference, that the air-discharge was 1,280 cubic feet per hour; but with the assistance of the gas-jet, burning some 3 to 4 feet of gas per hour, the ventilation was 3,170 cubic feet per hour; showing the great help to ventilation by a small quantity of gas properly applied. Difference of temperatures at floor and ceiling from 2° to 3° F.; four people generally occupied the room. To facilitate the work of the stoker he had a thermometer fixed to the "flow" pipe of the hot-water apparatus, and for several weeks he took careful readings of the external temperature, the temperature

Mr. Schönheyder.

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Mr. Schönheyder.

of the flow, and the temperature of the principal room, from which he constructed a Table showing what temperature should be kept in the flow pipe under a given external temperature in order to ensure the desired inside temperature. It worked so well that the inside temperature seldom varied more than 1° or 2°, excepting only through the occasional neglect of the night-watchman. In very cold countries the system of warming by hot air only was not satisfactory, as it necessitated a very high internal temperature of the air (70° was very general in American rooms) in order to counteract the chilling effect of the walls; in other words, the strong radiation of heat from the body to the cold walls. Some system of double walls, say brick external and thin internal of iron, wood or cardboard, with a system of heating pipes between, would probably be found efficacious for all walls communicating with the external air, proper ventilation being provided for.

Prof. Smith.

Prof. R. H. Smith observed that an approach to theoretically perfect ventilation would render possible considerable economies in building construction. The commonly adopted basis of calculation of so many cubic feet of space in each room per person meant that the object aimed at was the slowing down to a standard time-rate of the vitiation of a stationary quantity of air. From this idea was derived that of supplying per hour between 30 and 200 times as much fresh air as was actually inhaled by the living inmates of the room. The true idea of perfect ventilation was evidently to inject and extract only a moderate excess, say 5 to 10 times as much, over that actually inhaled, and to do so in such manner, that (1) the exhalations did not mix with the fresh supply, and (2) the inflow was properly diffused and did not pass direct to the outlets in merely local currents or "draughts." To do so under these conditions was admittedly a mechanical problem of the greatest difficulty, but one which ought not to be considered insoluble. With such ventilation small bed-rooms and living-rooms with low ceilings would be more sanitary and more comfortable than large ones with lofty ceilings without such ventilation. Except for architectural effect, high ceilings mean simply the provision in the upper part of each room of aerial cesspools—a plan which was both insanitary and disgusting. He had examined several cases of large complex ventilation installations on the plenum system, and found it unsatisfactory unless under careful, skilled and continuous supervision. Air being so light a substance, the small differences of pressure in the outside atmosphere arising at one place every few seconds, and simultaneously on different faces of even a small building, were sufficient to cause back draught in one

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outlet duct finding its escape by increased forward draught in another. This difficulty was common to the plenum and extraction systems if the motive power of the forced draught of a complex system be concentrated at one place. The rational cure seemed to be the decentralization and proper distribution of this motive power in a degree proportioned to the ramification of the whole installation served. This might be accomplished either by electrically-driven small fans or by gas-jets properly protected from being blown out by back draught. Another help was the insertion of light check-valves placed near the extremity of each outlet duct. Mica-plate flaps could easily be made noiseless by providing them with wash-leather seats to fall upon. They should hang slightly open when no current passed. As the exhalations from the lungs did actually rise, the "down-current" or "ceiling-to-floor" system was incapable of producing the theoretically perfect ventilation alluded to above. Its advantage was the easier uniform distribution of the fresh-air current over the horizontal area of the room. Again, inflow at the floor invariably had chilling effects, and also swept the fresh air over a surface that could not be kept scrupulously clean. The perfect inlet would seem to be a perforated pipe running all round each room at a height of 3 or 4 feet from the ground; and the perfect outlet 2, 4 or more vents at the ceiling on opposite sides of the room. With perfect ventilation the quantity of inflow needed per hour was so small that the mechanical driving power required would be vastly decreased; the velocity of the air-current was so low that "draughts" would be much more easily avoided, and the heat that must be expended to warm the air to a comfortable degree was also correspondingly diminished. It might fairly be doubted whether any air-warming at all would be needed for perfect comfort even in the coldest weather. Living bodies were not warmed but cooled by contact with air, and the only utility of air-warming lay in the diminution of the chilling effects of draughts. Living bodies were warmed chiefly by internal combustion, and the only available external sources of heat were "radiators." Even in a hot bath at 105° F., the supply of heat by conduction from the hot water to the body must be very small, the main warming effect resulting from the complete or partial stoppage of loss of heat from the body. The suggested "perfect" ventilation was evidently imcompatible with warming by open fires placed near the floor. With these the main extraction was always at the fire-place.

Prof. Smith.

Mr. G. W. Walker agreed that where fans were employed, and in short tunnels, their best position was about the middle of the tunnels, extracting the foul air from that point and causing

Mr. Walker.

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Mr. Walker. the fresh air to rush in at either end. The Author stated that objection had been taken to this system of placing fans midway in the tunnel, as a strong wind blowing in at either end would effect the suction of the fan, *i.e.*, unbalance the sucking power of the fan, which might tend to pull more from the windward and might even neutralize the natural air-current on the lee side; he did not anticipate much difficulty on that score, natural currents being, as a rule, feeble. Atmospheric conditions caused natural currents of air in a tunnel. Sometimes they flowed in one direction and sometimes in the other, but the natural currents were quite inadequate for efficiently ventilating a tunnel, say, like the Severn or Mersey or even the Metropolitan. There were also other currents caused by the motion of the trains. If an anemometer were held from the window of a moving train, a strong current would be noticed in an opposite direction to that of the motion. But these currents did not ventilate the tunnel, they only stirred the stagnant mass of air. There was, however, a feeble current carried along with the train due to skin friction. This current would act as a ventilating one if the trains were always travelling in the same direction, so that a current of air, even if feeble, would be caused to flow in a definite direction. But this moving current was liable to be opposed and reversed by trains coming in the opposite direction. It was perfectly clear that trains did not act as pistons, nor could they efficiently ventilate a tunnel. He did not think the ventilation for tunnels was quite similar to that of mines. The air-resistance in mines was considerable, owing to the tortuous flues and passages, and a fan working at a high-water gauge was necessary. But the resistance in a tunnel due to its large sectional area was practically nil. In dealing with large volumes of air, great caution was necessary, or a considerable waste of power was liable to occur. In a tunnel ½ mile long and 400 square feet sectional area, the energy spent in moving 240,000 cubic feet per minute amounted to only 0·8 HP.; but if the volume of air had to be discharged through a duct 4 feet in diameter and 100 feet long, the velocity of air would have to be increased sixty-four times and the HP. varied as the square of the velocity, which would bring the HP. due to the increase in velocity up to 1,640, friction would absorb an additional 600 HP., and the HP. would thus be raised to 2,224 HP. There was no limit to the waste of power which might result in trying to force large volumes of air through a contracted opening. In the majority of cases of tunnel ventilation, 90 per cent. of the power was spent in trying to get the air through contracted outlets or through the fan itself. The latter

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might have a high efficiency measured by the work done, but 90 per cent. of this work might be spent in giving the air an unnecessarily high velocity. The ventilation of buildings might be divided into two main systems—the vacuum or extraction and the plenum or propulsion system. In the former the foul air was extracted, say, with an air-propeller, causing a partial vacuum in the room or hall, which caused the fresh air to rush in at various places. The pure air entered through openings in the outer walls, protected by grating, and passed over heating coils placed in the various recesses. The foul air might be extracted from the top or bottom of the room. In the plenum or pressure system the pure air was drawn from one central source, filtered and warmed, and forced into the room, the foul air being therefore forced out. The great advantage of the plenum system was that it gave complete control of the air, so that it was easily filtered and warmed. With the vacuum system it was difficult to say where the air came from; the air in the room being extracted, fresh air rushed in on all sides; and if a drain, sewer, or soil-pipe happened to be near, polluted air might be drawn in. It was also found that the chances of draught were greater in the vacuum system, the entering air might have a tendency to take a short cut to the fan, leaving the bulk of the air in a stagnant condition. The inlet should be, say, 10 feet from the floor; and from experiments in a Board School at actual work, it had been found that the best results were obtained when the foul air was taken off near the floor-level, which could not be wondered at when the amount of dirt and dust that every day collected on the floor in a Board School. This, together with the emanations from the children, should not be allowed to rise and pollute the air above, but should be removed before it could do harm. An interesting installation, which he had recently erected conjointly with Dr. Haldane, F.R.S., was that at the musical club room at Oxford University. It was on the plenum system and the air was heated by electricity. Dr. Haldane had written—"The whole seems now to work excellently, and the secretary of the club has simply to turn on the switch to get whatever amount of air and whatever temperature seems desirable. The room is kept clear of tobacco smoke, &c., and the complaints about headaches after the concert have disappeared. The allowance of air is about 1,000 cubic feet of air per person per hour." Mr. Walker.

Mr. A. T. Walmisley remarked that in large dining-rooms, with only natural ventilation, when lighted by electricity and several persons smoking tobacco, the smoke hung about the table or centre of the room, whereas if the air was heated at the top by a gas sun- Mr. Walmisley.

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Mr. Walmisley. burner or other means, and proper ceiling exits provided, the room was kept clear and comfortable. As to air space, in hospitals 1,000 cubic feet per patient was an approved minimum to allow in a ward, and this volume should only be reckoned 10 feet in height, so as to provide ample floor-area or space of 100 square feet. He would be interested to know the Author's opinion of the tunnel leading from the King's Cross (Metropolitan) station to the King's Cross suburban station upon the down line. It was the foulest tunnel that he knew, and worse than the Penge and Sevenoaks tunnels. The latter must be full of oscillations of foul air driven first in one direction and then in another by the passage of up and down trains. Would not a thin partition in the Penge and the Sevenoaks tunnels, centrally and longtitudinally, in the central way, separate the tunnel into two tubes, so that the trains help to push the foul air always in the same direction? This partition needed no great strength; it would serve purely as a screen. The Central London Railway engineers were wisely adopting separate tunnels.

Mr. Wilson. Mr. JOSEPH M. WILSON, of Philadelphia, stated, as an example of what he would suggest for special tunnel ventilation, that it had been his province as consulting engineer for a prominent railway company to recommend a ventilation system for a tunnel on a subway line in a large city, where the surface above was to be occupied as a street. The tunnel had a length of nearly 3,000 feet and was for four lines, having an area of cross-section of 1,022 square feet and a total content of about 3,000,000 cubic feet. It was practically a portion of a terminal yard in which shunting was carried on, and one or more engines might be in the tunnel almost constantly. The line was nearly level and there was no opportunity for natural ventilation, so that in murky, damp weather the smoke and gases from the engines would remain in the tunnel for a long time. Extraordinary precautions seemed necessary, not only for the comfort of the employees and passengers, but also to make it possible to work the tunnel without danger to life or damage to the property of the Company. It was recommended that four 20-feet diameter exhaust fans be located in pairs at two fan stations, so as to divide the tunnel into four equal parts of about 600 feet each, each fan therefore clearing one-fourth of the tunnel. Seventeen outlets were proposed for foul air, located in the roof of the tunnel, about 150 feet apart, each outlet having an area of 33 square feet, these outlets to connect with four main air-ducts, one to each fan. Upon the opposite side of the tunnel, midway between the outlets to the fan conduits, inlets were to be provided

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to deliver fresh air from the street above to the bottom of the tunnel, the distance from an inlet to its adjacent outlet, across the tunnel, being approximately 80 feet. The conduits to the fans and the outlets from the tunnel were to be proportioned to equalize the flow from all parts, and the inlets were to be protected by automatic louvres opening inwards, so as to prevent the possibility of the escape of foul air from the tunnel to the street, the outlets from the fans to discharge into tower-shafts 108 feet in height above street grades. Possibly at times both ends of the tunnel might be blocked with cars. The air inlets would then be largely depended upon to furnish fresh air. With a velocity of air in the fans of, say, 15 to 20 feet in a second, a full supply of fresh air would enter at distances of 150 feet apart, the fans emptying the tunnel every 6 minutes. The fans were to be operated by electric motors supplied with current from a central plant which also had other work to provide for. The tunnel was constructed under a joint arrangement between the City and the Railway Company; but the ventilation scheme, while fully elaborated in detail and approved of as the proper one for its purpose, was not adopted on account of its expense, and an arrangement was concluded between the Company and City for a series of longitudinal openings, aggregating in all about 6,500 square feet in area, constructed from the roof of the tunnel to the street on its centre line, this being a very wide avenue. These openings were walled up about 3½ feet in height above the street level, and were surrounded by beds planted with shrubbery so as to conceal them from the drives on both sides. It was not believed that, even under the most favourable circumstances, the adopted arrangement would accomplish all the fan system promised, and there would be times when it would undoubtedly be found ineffective; but, under the circumstances, it was the best that could be done. A number of anemometer readings had been made in the tunnel to determine, if possible, the action of the vent openings; but they were not very satisfactory, nor was it possible to arrive at any very definite conclusion. With many cases to the contrary, the following general conclusions had been reached. With strong currents in the tunnel there was less current in ventilating openings, while with a weak current in the tunnel there was a stronger current in vent openings. A weak current in the tunnel generally induced a reverse current in the vent openings. The current was generally weaker in the tunnel in the direction of its axis under the openings than between them. He had experience in the heating and ventilating large buildings,

Mr. Wilson.

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Mr. Wilson. hospitals, schools and other public structures, but in such cases each building had its own conditions and must be worked out as a special problem. For private residences, heated by steam, low pressure indirect radiation was generally employed, fresh air being drawn from the exterior of the building to radiator-boxes located in the cellar or basement, directly under the various vertical heat flues discharging to the different rooms. Flues for ventilation were provided to the rooms, occasionally connected to a common flue, where the draught was accelerated by a steam coil, and the windows were also available. Such a system brought in the heated air always fresh. In the Presbyterian Hospital of Philadelphia, which he had designed, nearly all the wards were of a single storey. Fresh heated air was admitted to the wards and rooms by indirect radiation, supplemented with direct radiation in some cases where specially needed, and foul air was taken off by flues from the floor under each bed, carried to a common flue. Open fireplaces were provided, and ridge ventilation in the ceiling or roof for summer use, or even in winter if desired. These ridge ventilators extended for nearly the whole length of the ward like the ventilators in an American Pullman car. The windows had a double-hung sash with a transom above, all movable, and the sashes were double glazed, there being ½ inch air-space between the inside and outside glass, so as to keep out the cold in winter and prevent down-draughts. The best practice had been followed as to square feet of floor surface, cubic content of rooms, etc., per patient. The best system for heating and ventilation was one with plenum fans driving in fresh air previously warmed to a certain temperature, say 70° F., by passing over steam coils; any extra heat required to be supplied in the rooms by direct radiation and controlled by thermostats operated electrically. The heated fresh air was introduced to the rooms by flues at a considerable elevation above the floor, and the foul air was taken out at, or close to, the floor, to exit shafts, the draught being induced preferably by exhaust fans. The fans were best operated by electric motors, and where engines were in service in the building the exhaust steam was utilized in heating. In such cases, while the dynamos were running, the heat costs practically nothing. Vacuum pumps were often used to promote circulation.

Mr. Worthington. Mr. EDGAR WORTHINGTON thought that the method of ventilating tunnels on mountain railways by completely closing the mouth after the entrance of a train might be found useful in many cases. It had several advantages over other systems, such as reliability, simplicity and cheapness, especially in eastern countries where

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labour was so plentiful. In the summer of 1893, while inspecting the Usui-Toge rack railway in Japan, for the purpose of designing the large four-cylinder locomotive engines, which had since been constructed and were now working this heavy traffic up the long 1 in 15 gradient, he had been requested by the Director of Railways to advise how to ventilate these tunnels, as all known methods had been tried without success. The locomotives on this section of the railway pushed the trains up the incline at a speed of about 5 miles per hour, and the carriage windows were all closely shut. He had observed, from the locomotive foot-plate, that the products of combustion gathered in the top of the tunnel, travelling both forwards and backwards, and being very little disturbed by the slowly travelling train. This dense mass of smoke and steam gradually increased in volume, and breathing became impossible, except through some filtering material; and before the end of the tunnel was reached the water-gauge lamp, which had previously burned brightly, went out, and the two Japs on the foot-plate were kneeling with himself with their faces as low as possible to breathe what little oxygen there might be left at the bottom of the tunnel. After this experience he had recommended the Japanese Government to erect a canvas screen at the lower end of each of the worst tunnels, this screen to be closed after the entrance of each train to prevent any air following the train. This was soon done, and proved successful. The new locomotives were designed so that the engine-men could also breathe air from the rail-level, in case the screen arrangement proved inefficient. Mr. Worthington.

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13 December, 1898.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

The PRESIDENT said that for the third time since he had been President of the Institution it was his painful duty to have to announce a gap in the ranks. In his experience, and in that of the Council, no President had ever been so unfortunate. He had to announce, what perhaps the members already knew, the sad and irreparable loss sustained by the Institution in the death of Sir William Anderson. The Council had, of course, taken the matter into consideration at once, and had passed the following

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resolution:—"That the Council have learnt with deep regret of the death of Sir William Anderson, Vice-President, and desire to convey to Lady Anderson and the members of the family an expression of sincere sympathy with them in their bereavement." The President, continuing, said he doubted whether there was any member who had sat at the council table whose loss would be more deplored than that of Sir William Anderson. Not only would he be missed as an engineer of the very first rank, but he was one of those men who instinctively seemed to attach everyone to themselves. His word to everybody was law, and his judgment was so sound and so pure that he only had to express it to be accepted. But apart from his high character as a man, there was one rich side of his nature which his personal friends knew so well, and that was, that he was a true and a perfect Christian. His son had told the President that in his last moments the nurse thought that he was wandering, and the son put his ears to his father's lips, and there he heard his father doing what he had been in the habit of doing for twenty-five years—addressing the little children in the Sunday School attached to his home at Erith. It was a very touching illustration of the character of the man, and he (the President) could not resist the temptation of bringing it before the members.

The discussion upon the Paper "The Ventilation of Tunnels and Buildings" occupied the evening.

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20 December, 1898.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

The discussion upon the Paper "The Ventilation of Tunnels and Buildings" was continued and concluded.

SPECIAL GENERAL MEETING.

THE following Notice convening the Meeting having been taken as read :—

NOTICE IS HEREBY GIVEN that a Special General Meeting of The Institution of Civil Engineers will be held at the Institution, Great George Street, Westminster, on Tuesday, the 20th day of December, 1898, at a quarter past 9 o'clock, for the purpose of considering, and, if approved, enacting a supplemental By-law to the following effect :—

SECTION VI.—CLAUSE I.

The year of office for the President, Vice-Presidents, and other Members of the Council, shall commence at the commencement of each Session, and the election of the Council at the Annual General Meeting for the ensuing year, and the appointment of other Members of the Council for the same year, shall have reference to the next ensuing year of office as hereby defined.

The existing Council shall in all cases continue in office till the commencement of the next Session, notwithstanding that more than a year may have elapsed since the commencement of their year of office.

J. H. T. TUDSBERY,
Secretary.

Great George Street, Westminster,
12 December, 1898.

the Chairman, after explaining the object to be effected by the By-law, moved, and Sir Douglas Fox, Vice-President, seconded, and it was unanimously Resolved :—That the following be added to Clause I of Section VI of the By-laws :—

"The year of office for the President, Vice-Presidents, and other Members of the Council, shall commence at the commencement of each Session, and the election of the Council at the Annual General Meeting for the ensuing year, and the appointment of other Members of the Council for the same year, shall have reference to the next ensuing year of office as hereby defined.

"The existing Council shall in all cases continue in office till the commencement of the next Session, notwithstanding that more than a year may have elapsed since the commencement of their year of office."

The Meeting then ended.

(Signed) W. H. PREECE,
Chairman of the Meeting.

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10 January, 1899.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

FRANCIS PHILIP ANDERSON.
FRANK BAILEY.
ROBERT HENRY BICKNELL.
GEORGE WOULFE BRENAN.
ISAAC CARR.
GEORGE MAXWELL LAWFORD.
HUGH MAIR.
WILLIAM HENRY PATCHELL.
JOHN HENRY TAYLOR.
PEREGRINE OLIVER WILSON.

And that the following Candidates had been admitted as

Students.

RUPERT STANLEY ALLEN.
KENNETH ALFRED WOLFE BARRY.
THOMAS WILLIAM BUCKNEY.
ALBERTO ULISSE CALVI.
JAMES CONACHER.
ERNEST PERCY DOVE.
PETER DRUMMOND, B.Sc. (*Edin.*)
ERNESTO FERRO.
LINDOW HEREWARD LEOFRIC HUDDART.
GERALD EDWIN HULL.
WILLIAM AUSTIN HUTTON.
IVOR WILFRID JENKIN.
CLIFFORD LAKIN-SMITH.
DONALD HENRY LEA.
NORMAN AUSTIN LEECH.
WILLIAM ARTHUR LINSKILL.
GEORGE THOMAS BARNES MARTIN.
FRANCIS SAMUEL MILLER.
HENRY CECIL EARLE NEWTON.
HENRY LAWRENCE PEARSON.
NORMAN CLIVE SAWERS.
ROBERT HENRY EDMUND HUTTON SQUIRE.
GILBERT MILLER THORNTON.
REGINALD BRAMLEY TYRRELL, B.A., B.A.I. (*Dubl.*)
EUSTACE BALL WALTON.

The Candidates balloted for and duly elected were: as

Members.

THOMAS WALTER BARBER.
ROBERT JOHN BILLINTON.
DAVID EVANS.
WALTER THOMAS GOOLDEN, M.A. (*Oxon.*)

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Associate Members.

HENRY CHARLES ADAMS, Stud. Inst. C.E.
CHARLES WILLIAM ANDERSON.
JOHN BALL, Ph.D. (*Zürich.*)
WILLIAM STEWART BECHER, B.A.I. (*Dubl.*)
ROBERT FARRAN HANNA, Stud. Inst. C.E.
JOHN LLEWELLYN HOLMES.
FEARNSIDE IRVINE.
JAMES KEITH, B.Sc. (*Glas.*)
PERCY RAYMOND MCDOUGALL, M.A. (*Cantab.*)
JOHN MALCOLM, B.Sc. (*Glas.*)
COURTENAY EDWARD MOORE, B.A. (*Dubl.*)
SYDNEY WILLIAM MOORE, B.A. (*Dubl.*)
EDWARD LLEWRWG MORGAN.
EDWIN BENNETT BRIERLEY NEWTON, Stud. Inst. C.E.
WALTER BISHOP PURSER.
WILLIAM PAGE ROBINSON.
JAMES WILLIAM LAWRENCE TOOZS.
WILLIAM BEATTIE VENTERS, B.Sc. (*Glas.*)
FREDERICK SYKES WHEAT.

Associates.

ALEXANDER MACMORRAN, M.A. (*Edin.*), Q.C.
KUMAR NUR SINGH RANA (*Bahadur*).
THOMAS WILLIAM RIDLEY.

(Paper No. 3089.)

"High-Speed Engines."

By JOHN HANDSLEY DALES, Assoc. M. Inst. C.E.

SINCE the introduction of high speeds of rotation in steam-engines, various efforts have been made to avoid or overcome the difficulties and inconveniences resulting from knock and heating in the bearings. The most notable successes were brought about by the use of single-acting pistons, as in the Brotherhood, Willans and other engines of similar design; where the working pressure, being always in one direction, did not cause knock, even with slack bearings, so long as they can be prevented from leaving their journals, owing to the effects of momentum. This, however, required a degree of compression which largely reduced the useful effect of any given size of engine; and was also difficult to maintain under varying loads and pressures, the mischievous momentum being constant. The late Mr. Willans overcame this difficulty by the introduction of the air-cylinder. But the necessity for two sets of cylinders, the increased friction, the cost and the drawbacks incidental to single-acting engines, have induced efforts from time to time to place the double-acting on the same footing as the single-acting engine in the matter of quiet running; in order to obtain the benefit of some of the undoubted advantages of the double-acting type, not the least being its capability of running practically at any speed. The difficulty of attaining high speeds of rotation in double-acting engines arises from liability to

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heating when the adjustments are sufficiently close to avoid knock. At 300 revolutions per minute of an 8-inch stroke engine, a very audible knock will occur with a $\frac{1}{500}$ inch clearance in the bearings, and if the speed be increased to over 400 revolutions per minute that amount of clearance must be reduced to ensure quiet running; in fact, an actually close adjustment would be required. Such an engine would have at least a $3\frac{1}{2}$-inch shaft and $1\frac{1}{2}$ inch of brass in the bearings, and an increase of temperature of 20° F. would expand these more than the $\frac{1}{500}$ inch of clearance mentioned. Such a rise in temperature is not great in practice, and always occurs, so that it is evident that a double-acting engine with fixed bearings, running at high speeds, must either be allowed to knock more or less or run imminent risks of over-heating and seizure. If a bearing warms slowly, the surrounding parts expand somewhat; but when a bearing becomes heated, the rise in temperature is generally rapid, and the expansion of the source of heat overtakes that of the radiating parts. Formerly, merely taking up the wear appeared to be the chief object, and this was easily accomplished, but it was soon found that this was not the only point to attend to, and that in fact the slack very soon required letting out again. This did not appear to be easy, and the automatic "take up" was not successful. When an engine so fitted ran hot, it seized, and so a reversion to the fixed adjustment had to be made. An engine had to be started with knock, and was allowed to run as long as it would, or until the nuisance and noise were more than could be tolerated; then it was adjusted. It soon became clear that no dependence could be placed upon a bearing being by any means kept at a uniform temperature, and that the starting temperature; and it was equally clear that as a bearing which was closely adjusted became warm by running, it would have to be eased by some means, and at the same time the adjustment would have to be maintained. It therefore follows that a perfect bearing for high-speed double-acting engines must not only have an automatic close-up adjustment without pressure, but must also provide for the expansion due to the increased temperature which must always occur in engines running at high speeds. These features have been successfully embodied in the design of an arrangement which forms part of the subject of this Paper.

Previously to the introduction of this improvement, the Author made elaborate tests of apparatus, which, by means of differential pawls and the like, adjusted the brasses of reciprocating parts to within about $\frac{1}{300}$ inch, but in no case close up, leaving only

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an admissible knock at, say 200 or 250 revolutions; but he found that when the bearings did run hot through neglect, they seized similarly to any other fixed bearing, and that a knock which was out of reach of the expansion of the parts, was by no means admissible. The improvements to be described, with the object of eliminating knock, have facilitated the attainment of extraordinarily high speeds, and appear to have solved the problem of running to a much higher limit with double-acting engines.

An engine in which the improvements are embodied is illustrated in Figs. 1, Plate 1. The principal arrangements consist of an automatically adjustable bearing, which is applied to all parts subject to a reciprocating action; and of a radial shaft-governor in which inertia and friction are reduced to a minimum, and in which the mechanical relations of the parts are constant. The speeds attained by these means have developed effects which are not noticeable at low speeds, and which have been dealt with as they have arisen. The result is an engine which, with ordinary attention and ordinary lubrication, will run without heating at 30 per cent. to 50 per cent. higher speed than an engine with fixed bearings. The practicability of running any engine at very high speeds is largely a matter of design; but, so far as the bearings are concerned, the limit of speed which may be attained by the means in question has apparently not been reached. When a bearing which is subjected to a reciprocating action can be run without knock or other pressure than that due to the work upon it, vibrations due to indirect forces developed by the parts of an engine will determine the practicable limit of the speed of rotation.

A main bearing of a vertical engine crank-shaft fitted with the arrangements is shown in Fig. 4, Plate 1. The bottom brass is practically fixed as regards adjustment, while the top brass lies loosely on the journal. Over the top brass, and bearing upon it, is arranged a small hydraulic ram, which is packed to hold liquid at high pressure. The ram cylinder forms the gland, and is screwed into the bearing cap and on to the packing. The top of the cylinder is formed of a screw plug, by which the clearance behind the ram may be adjusted to allow of the expansion of the parts due to the heat of running. This is usually set to admit of an increase of temperature to 400° F. The upper part of the cylinder forms a reservoir for liquid, and in the screw-plug there is a passage from the reservoir to the interior of the ram cylinder. Between the ram and reservoir, and in the passage mentioned, a ball back-pressure valve closes the passage from the inside of the cylinder, in such a manner that the liquid may pass from the

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reservoir to the cylinder, but is prevented from returning. The arrangement is completed by a spring inside the ram which bears against the top of the cylinder with sufficient force only to drive the ram through its packing at such times as there is no working load on the top bearing. When the ram is projected downward on to the top brass, the space at the back of the ram is filled with liquid from the reservoir; but, on the pressure of the working stroke of the piston coming on to the liquid, the ball-valve is instantly closed, with so little back leakage as to be inappreciable, and the brass is held in its position by the liquid, which is practically incompressible. This action is repeated at every up-stroke of the engine. The lift of the ball-valve is about $\frac{1}{180}$ inch. The slight back leakage, as well as the slight compressibility of the liquid, causes the valve to work stroke by stroke as before stated; but if this were not the case, no hydraulic pressure due to increased temperature of the liquid could accumulate on the ram, owing to the impracticability of making any metal valve tight against a fluid pressure simply by that pressure bearing upon it. The certainty of the action of this simple contrivance is remarkable. Engines running at 600 revolutions per minute have been constructed with these bearings, but no perceptible difference has been observed in the action of the valve to that at lower speeds, and the limit of rapidity with which it would work is plainly far above the speed which can be attained by any steam-engine.

Modified arrangements of the same principles are applied to the main connecting-rod and the valve-rods. In the main connecting-rod, Figs. 2, the outside end brasses are fixed; that is to say, they are not adjustable by the automatic arrangements, but the two inside brasses are loose and adjustable. This arrangement of the adjustment on the inside brasses is a matter of convenience in the construction of the rod. In one design there are two rams, one behind each brass, with a spring and an inlet from the reservoir common to both. The reservoir differs from the main-bearing reservoir, inasmuch as it is provided with a loaded piston which follows up the liquid as it is expended by leakage, and also prevents its churning and aeration by the action of the rod. The back-pressure valve, between the reservoir and the space at the back of the rams, is similar to the main-bearing valve. When only a single ram is provided, both the cylinder and the ram perform the adjustment, the cylinder being guided in a slot in the rod. The reservoir is similar to the former, but is contained in the ram cylinder casting. In another arrange-

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ment of double ram, with back-pressure valve as before, the leakages are renewed by a dropper in the same manner as the lubricated parts of the engine. As it is important that no air shall be drawn into the cylinder, the liquid passes through a trap-valve and into a small reservoir which is always kept fully charged by the dropper; the trap-valve maintains a body of liquid in the passage in contact with the back-pressure valve proper. Similar arrangements are applied to the valve-rods, Figs. 3, the adjustment in both cases being carried to the small end brasses by means of a tubular pressure rod.

In running unusually high speeds with these engines, interesting points in lubrication have manifested themselves. When newly-bedded brasses with properly graduated easing off at the sides and imperfect contact on the bedded parts were placed in the bearings, they ran cool at any speed or with any pressure in a very remarkable manner, with ordinary single lubrication; but, when the bearing surfaces became perfectly bedded by wear, even with considerable end-play, they ran hot. It then became evident that, with close adjustment on both brasses and no pumping action on the bearing surfaces, lubrication would have to be provided for both brasses separately; as insufficient oil passed over a close fitting bearing to supply a second brass on the same journal, after part of it had been scraped off in the joint space. Various methods of channelling the surface were tried, but without beneficial effect. Finally, after supplying the brasses separately with oil, no channels were used, for it was found that when sharp edges wore on them, they scraped off the oil instead of leading it into the bearing surfaces. It is now well known that inclined leading-in surfaces for lubrication are necessary on all heavily loaded bearings; so, in order to provide this feature in as permanent a form as possible, all the bearings in these engines have been reduced to a 90° contact. This also prevents the closing-in of the horns of the brasses, and the troubles resulting from it. Intermittent pressures of 400 lbs. on the square inch of actual lubricated surfaces of contact in the main bearings run practically cool, and about double that amount appears to be admissible in the large end of the connecting-rod at surface speeds of 400 feet to 500 feet per minute.

Protracted trials of gun-metal bearings without white-metal have been made, in order to ascertain if any method of lubrication would obviate the necessity of using white-metal on soft steel cranks. It was found, however, that whilst no difference in friction or otherwise could be ordinarily detected, in case of

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accidental heating through failure of lubrication and the like, gun-metal bearings damaged the shaft journals, whilst white-metal might be melted without any such damage occurring. The objection to the use of white-metal was its liability to melt out, and the consequent risks to the engine when running at very high speeds; so, in order to secure the safety of gun-metal and the softening properties of white-metal, a double screw-thread, of such a width and pitch as will overlap any running track on the journal in a 90° contact, is cut in the gun-metal bearings, and the white-metal is run into the grooves after they have been tinned. This appears to act well and to answer a double purpose. When the white-metal becomes warm it expands more than the brass, in the ratio of about 12 to 10, and the journal is thus carried on the white-metal, so that the wear takes place on it; but when the bearing cools, the white-metal sinks below the brass and the journal rests on the latter. This will in both cases make shallow oil channels alternately on the brass and the white-metal. The running polish on the journals indicates this action, which is useful for lubrication. The brass thread is a safeguard against dangerous knock in case the white-metal melts out. Bearings lined in this manner will run for long periods, without heating, in a very remarkable manner.

There can be no doubt of the extreme desirability and importance of close governing. It is in all respects economical, producing both better quality and an increased quantity of work from any given plant. This is generally admitted, but the commercial value of the benefits to be derived from increased plant efficiency in this direction are usually much underrated. It is now known that by suitable arrangements governing can be effected from full load to no load, with no greater total variation of speed than 1·0 per cent. to 1·5 per cent. Until recently 5 per cent. to 8 per cent. variation was considered good governing. Very few engines at present run so nearly uniformly as 5 per cent. variation, and it will be quite fair to say that an average of 7 per cent. variation is well within the range of ordinary governing. It is obvious, then, that 5 per cent. more work might be turned out by an average plant if fitted with first-class governing, simply by an increase of 5 per cent. in the coal bill, every other charge remaining the same. A moment's inquiry will show the commercial value of this 5 per cent. increase of work. As an example, the electric light installation of a large provincial city may be cited, in which the sale amounts to 700,000 Board of Trade units per annum at about 6*d.* per unit. The total actual

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receipts are £15,500, 5 per cent. of this is £775 per annum, while the total coal bill amounts to only £850. Each 1 per cent. in this case has a value of £146 14*s.* per annum, after deducting an increase of 5 per cent. on the coal bill. Again, in the case of a large woollen mill, the coal bill was 2½ per cent. of the wages item, and the governing, which was ordinarily good, was within a 5 per cent. variation. In this case the saving to be effected by the best governing would be equal to the whole of the coal bill. The term "variation" is here applied to the total range of speed, and not a deviation from the normal.

As to the possibilities of governing by the various types of governor in ordinary use, an apparatus was made as early as 1876 by Mr. H. P. Holt of Leeds, and experiments, with which the Author was entrusted, were made to ascertain the friction of governors. A dead-weight loaded governor, with hard-steel pins in the joints, of unusually small diameter and great length, and compensated by springs to practical isochronism for change of position, was tested under the most favourable conditions which could be provided. It was found that no change of position could be brought about by smaller observable variation than 1½ per cent. in speed from the normal, so that for a double change of position up and down, a total variation of 3 per cent. for friction alone was required. It was thus obvious that as the minimum friction was 1½ per cent., no adjustment of the variation of the governor due to position, between full load and no load, could be made nearer than 2 per cent. if no racing should take place. The friction of repose in this case was 1½ per cent., therefore the friction of motion would be 1 per cent., which, added to the rise variation of the governor, would be 3 per cent., and, together with 1½ per cent. friction in the opposite or falling direction, would make a total variation of 4½ per cent. as the nearest possible arrangement and adjustment of such a type. No account is here taken of the effect of inertia on any sudden change in the engine, or of any work to be performed, and this would therefore be an impracticable adjustment in an ordinary case; that is to say, in ordinary work with such an adjustment of such a type of governor, racing would occur. To the Author's knowledge single governors of this class, without compensation, applied to Corliss engines have a total variation of 9 per cent. between no load and full load.

A governor of such design with compensation for change of position and having for its size practically no work to perform, was applied to a large mill-engine, and was carefully tested; and

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the smallest total variation, that is, range of oscillation, with which a change of work could be made was 4 per cent., but a sudden variation caused a much larger fluctuation in speed. This was a large governor and its friction was in consequence somewhat less in relation to its centrifugal force than a smaller one would have been.

Subsequently an inverted spring-load governor was designed and was applied to a large blowing-engine having a fairly steady load. This governor ran at a comparatively high speed and worked a throttle-valve. A careful test showed the friction to be about 1 per cent., and it was set to a 2 per cent. difference for change of extreme position, and actually governed the engine to which it was applied to a total variation of 4 per cent. This governor had a very short range on the slider. The most careful adjustment and manipulation could not improve this result with this governor. It must be borne in mind that these examples were fitted with plain pin joints, but that the whole were very carefully designed.

The difference in friction between the two, both having the same kind of joint, may be accounted for by the fact that the load in the first case was hung on three pairs of pins, while in the second the spring load was taken by only two pairs of pins; and, moreover, the inertia of the dead weight would cause an extra cross strain and friction on some of the pins, or on a sliding key on the upright spindle.

In 1888, the Author, having to provide very fine governing and at the same time great power for working heavy expansion-gears, determined to try ball-bearings in extra high speed inverted-spring governors in connection with auxiliary power for the purpose. The governors were very carefully designed as regards mechanical variation, and the ball-bearings were applied to every joint and link. The effect was remarkable. The inertia was very low, the total centrifugal weights amounting to only 5 lbs., while the spring load was 360 lbs., and the speed of revolution was 400 per minute. The friction was a practically negligible quantity, that is to say, the most delicate speed-indicator had less motion than the governor itself, which showed every stroke and varying impulse of the engine; it was possible with these arrangements and the auxiliary power to govern the engines to which they were applied to 1 per cent. total variation under any change of load. A later application of the same appliances to a pair of engines with cranks at right-angles, a very light fly-wheel, and a 12½ per cent. maximum impulse, governed

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to 2½ per cent. total variation. A nearer adjustment than this caused racing. The speed of this engine was eighty-five revolutions per minute; with a higher speed and heavier wheel a much nearer adjustment could have been made.

More instances might be cited, but perhaps sufficient indication has been given of the direction in which good governing may be obtained—that is to say, by the maintenance of constant or regular mechanical relations of parts, the avoidance of change of direction of centrifugal forces, and the elimination of inertia and friction. It cannot be too definitely stated that practically no working force can be obtained, if close governing is required, from even the most powerful centrifugal governor. It must be designed and constructed to be simply a perfect centrifugal-force generating instrument which can be adjusted to practically perfect isochronism. It is not necessary, for the accomplishment of good governing, to diminish, by the provisions required for the same, the ordinary economies of steam-consumption, but, on the contrary, such provisions rather add to such economies. It is obvious, however, that if simpler engines, in regard to compound expansion provisions than some ordinarily in use, be necessary for the accomplishment of the best governing, there is still a large margin of profit in its favour.

In designing a governor, to be now described, it was sought to produce a shaft- or fly-wheel governor, which would attain the results previously referred to as having been obtained from a ball-bearing high-speed governor, and the points necessary were laid down as follows:—1st, That there should be no change of direction of the centrifugal stresses; 2nd, that such stresses should be directly radial; 3rd, that friction and inertia should be reduced to a minimum; 4th, that the mechanical relations should be constant; 5th, that the inertia of the governor, though very small relatively to its centrifugal forces, should be as far as possible in excess of that of the driven parts of the expansion motion.

These points were embodied in the arrangement shown in Figs. 5 and 6, Plate 1. The centrifugal weights consist of the spring-boxes and attachments, as also of the load springs. Any alteration of the cut-off is brought about by revolving the cut-off eccentric on the engine-shaft by the action of the governor, and so advancing its centre as regards the time of the engine. An extension of the cut-off eccentric boss forms a sleeve on which is keyed a spur-wheel. The spring-box slides are formed of rectangular bars, which are bored longitudinally to work on round guide-rods, and the slides are fixed rigidly to the spring-boxes by suitable

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lugs. Rack teeth are formed on these spring-box slides, which are on opposite sides of the box. The teeth of one rack in each spring-box are made to gear into the spur-wheel on the eccentric boss, but on diametrically opposite sides, so that in performing their functions they partially rotate the cut-off eccentric on the engine-shaft. The second or idle rack of each pair is provided as a centrifugal balance to the first for preventing any cross stress on the guides, and also for reversing the direction of the cut-off of the engine, as will be shown. The idle rack is made to miss the spur-wheel by placing the centres of each pair of guides in a diagonal position with regard to the plane of motion of the governor. The spur-wheel on the cut-off eccentric is made with a collar or boss on one side a little wider than the teeth, so that by reversing the wheel on the sleeve its teeth engage in what were the idle racks, which, in performing their functions, turn the eccentric sheave in a direction corresponding with a reversal of the motion of the engine. The general arrangement of the governor is one of great simplicity, and the forces to be developed are all easily ascertained, except those of the spring upon itself. The effect of the centrifugal force of each coil upon the general closing of the spring differs from the inner to the outer end, becoming less and less per pound of centrifugal force, while at the same time the centrifugal force of each coil increases as the radius. The stiffness and range of the spring must harmonize with these differences, and also with the centrifugal force of the spring-box, and the variations of radii of all these factors.

The centrifugal force of the spring-box and attachments are ascertained separately, but the effect of the spring upon itself may be calculated from *Fig. 7*, which is simple and self-checking. The weight of the separate coils, of a given stiffness and length of spring, is ascertained by calculation and experiment, and on a centre line corresponding with a radius running through the spring is laid out the distance of each coil in the open position of the spring. The centrifugal force of the outer coil is then laid off to scale as an ordinate, and a line is drawn from the end of that to the centre of rotation, giving the centrifugal force of each other coil by the length of its ordinate. It is desired to ascertain the effect of each item of centrifugal force on the inner or head end of the spring, and for this purpose the different ordinates are reduced to the base or root of the spring, from each point so obtained lines being drawn to the centre of the root of the spring, where the effect of such centrifugal force disappears. The reduced ordinates procured in this way represent

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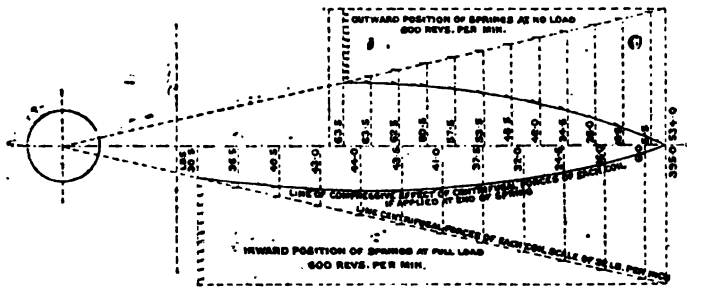
the effects of the centrifugal forces of each coil in closing the spring. This process is repeated on the outer positions of the spring coils on the opposite side of the radial line first laid down. It is clear that the sum of the ordinates in the inner and outer positions respectively represent the closing effect in each; and the difference of those sums will be the proportions of the variation of resistance of the spring required to balance the centrifugal force of the same in the two positions referred to. The corresponding differences of centrifugal forces of the sliding weights, added to those of the spring, will be the increase of resistance required between the inner and outer positions, which, divided by the range in inches, will give the stiffness per inch of compression of the spring.

Fig. 7.



Scale, ½ inch = 32 lbs.

DIAGRAM SHOWING CENTRIFUGAL EFFECT OF EACH COIL OF SPRING.

Initial compression prevents any action of the governor until that speed is reached for which the whole arrangement is designed.

Having found an exact balance to the centrifugal forces of the sliding weights and spring, a proportion of stiffness is added to the spring which will provide for the increase of speed between the inner and outer positions of the governor, which is necessary to prevent "racing." In the example shown, this increase is about 1 per cent. No sufficiently careful tests have been made for the determinations of the friction of this governor, but it is so little that very delicate apparatus would be needed for the purpose; an 8-inch stroke engine is now driving a 25-kilowatt dynamo at the Barry Docks, and the speed just off the governor stop is 480 per minute, while at the zero limit of the light load it is only 485.

No difficulty has been experienced in obtaining springs of sufficient range and accuracy. The rack and wheel has been

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adopted, as the only double-acting coupled connection between the governor and cut-off motion, which has practically no mechanical variation. Any regular mechanical variation can be dealt with by a spiral spring, but an irregular variation, such as would be produced by any link working through the angular distance required, could not practically be so dealt with. Any slack in the teeth has no effect, and causes no rattle, as the pull upon them is in one direction only. The mechanical advantage of the inertia of the governor to that of the parts of the cut-off motion is 3 : 1, and with this the reciprocating action of the valve produces no observable effect on the governor, the sliding parts of which are apparently perfectly steady. Tests have been made from 300 revolutions to 600 revolutions per minute with the governor just off the stop, but no dancing motion could be detected. There is no difficulty at high speeds in observing the action of the parts of the governor, seeing that in a ray of light they appear to be stationary.

With reference to the centrifugal power of these governors, it may be stated that, at 600 revolutions per minute of a 42-inch governor wheel, the maximum load in the two springs is about 4,000 lbs., the initial load being about 2,000 lbs., and that in the general running position about 3,000 lbs. The centrifugal dead weights amount to about 60 lbs., or about 2 per cent. of the spring load.

There appears to be little doubt that the use of an efficient governable cut-off gives the best results of close governing, in addition to increased economy of steam, though the small difference in the latter is the less important consideration. Throttling was introduced to govern engines having practically no cut-off and in which 1 per cent. variations were not looked for. A throttle-governor is in its nature only fitted to govern perfectly a true rotary engine, that is, an engine of constant draught on the pressure supply and with a constant torque corresponding with the work to be performed. By its principles a centrifugal governor can perfectly control a continuous stream of pressure passing through a throttle-valve with any range of variation of speed which is greater than the friction variation of such governor, and without any other motion than a simple change of position which is required for increasing or decreasing the supply; but such a stream of pressure can only be received by a true rotary engine and cannot be dealt with by any reciprocating engine. The moment any cut-off or interruption of the pressure-supply takes place, the governing necessities of the altered condition begin to

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run counter to the possibilities of throttle governing, and an imperfect result ensues.

To perfectly control a reciprocating engine having any cut-off, a throttle-valve would have to close at the cut-off time, in order to prevent accumulations of pressure on the engine side of the throttling point; and it must therefore virtually act as a cut-off, the oscillatory motion for which would have to be brought about by a simultaneous variation of speed throughout the whole engine and everything connected with it. This is the very effect which governing is intended to avoid. On the other hand, no governor has any value which does not move its slide or equivalent at every stroke of an engine, but the movement brought about by the impulse of an engine is through so small a range as to be insufficient for throttle cut-off governing purposes, especially at high speeds of rotation, when inertia would interfere with such an action.

A correct throttle governor would have to be of the spring-load type, with practically no inertia, of such proportions that its natural oscillation was equal to that of the speed of the engine to which it belonged, and it should have no work to perform. The range of the oscillations producing the valve action would have to correspond with the impulses of the engine, and, given the possibility of making all these things match, they would only be correct at one speed.

Altogether, throttle-governing of any high quality would be very difficult of accomplishment. Cut-off governing, on the contrary, is quite different and easy. The intermittent steam-supply is provided by the cut-off valve and its quantity by the position only of the governor. What is needed is a perfect centrifugal-force generating instrument, of sufficient quantity and inertia to withstand that of the cut-off motion without undue influence from the latter. No other motion of such an instrument is required than a change of position brought about by a change of speed, corresponding with the requirements of the steam-supply. There are no free forces concerned except those of the governor itself, which are practically uninfluenced; while in the case of throttle-governing the whole of the operating forces are free, and consequently efficient provisions for their variations and deviations are difficult to the verge of practical impossibility. The faster an engine runs the easier it is to govern, especially by throttling.

It is known that with high pressures and high speeds very ample port-areas are required, chiefly on account of the density of

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high-pressure steam, but largely also on account of the rapid reversal of the currents in the port; also, relieved valves are practically necessary on account of the size and the heavy friction of anything of the sliding type, so that it may be said that piston-valves are indispensable at very high speeds. Of the several constructions of these, the solid valve, well fitted in a hole, has the important advantages of light friction and light weight; and at very high speeds it is practically as tight as any other, the percentage of loss by leakage being probably less than that of the friction of rings of any kind added to their leakage losses. Cast-iron solid valves in cast-iron cases properly lubricated are found to answer perfectly well at any speed. Relatively large steam-openings of the valves are necessary features in engines of the type under consideration, and these must be obtained by relatively small eccentrics in order to avoid high periphery speed as far as possible.

The engine which is illustrated in Plate 1 was designed entirely for obtaining speed without regard to steam-economy, free running being the first consideration. The ports are fifteenths and tenths respectively, for steam and exhaust, of the area of the cylinder; and they are extended to give a direct action of the distribution-valve from its eccentric, which is placed outside the main bearing of the crank-shaft. No lap was made on the distribution-valve in order to keep down the size of the eccentric, and consequently there is scarcely any compression in the cylinder. The cut-off was placed in a separate bore and was arranged to take effect always at five-eighths of the stroke of the cut-off eccentric, the variation in the cut-off time of the engine being brought about by advancing the cut-off centre as before stated. The cut-off action is consequently always at the highest rate which can be obtained by the stroke of the eccentric employed. The stroke of the engine is 6 inches, and the speed of revolution 600 per minute. The crank-shaft was made as small in diameter as was deemed advisable, to keep down the surface speeds. All these measures were precautionary and experimental. The results have proved that in all respects there is a large margin. Running at the speed mentioned is easy, and the ball-valve in the adjustments shows no difference in its action from that at lower speeds. There is not more than 3 lbs. to 5 lbs. per square inch loss of pressure out of 80 lbs. between the steam-chest and the cylinder; the engine runs remarkably cool all over, and the friction when new, after repeated tests, was found to be not more than 5 per cent. of the full load.

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At high speeds, the absence of undue vibration, without the ordinary compression, strikingly illustrated the value of a close-up adjustment; and at the same time demonstrated the steadiness of turning which can be obtained from a high grade of expansion in a single cylinder, when the effect of the inertia of the parts of a high-speed double-acting engine can be utilized. The best effects were obtained when the speed and pressure brought out the line of the tangential force from that of the path of the crank, at or about a tangent, to the point of the commencement of the stroke. There was a striking absence of vibration in the engine under these conditions.

The trials proved that very high speeds, consequent high power in small compass, and every economy of steam and engine friction, which can be obtained by any means, can be easily obtained from double-acting engines when fitted with bearings which enable the designer to disregard the ordinary difficulties of high rates of rotation.

In order to ensure the safety of the cylinder against priming accidents, the valve-bores are not made in the cylinder casting, but in a separate one, which is provided with suitable passages, and stands against an ordinary port-face in the same way as a slide-valve, but which does not slide. This valve-casting is kept on the port-face by the steam-pressure in the chest, in which there is sufficient space at the back of the casting to admit of its leaving the port-face and acting as a large relief-valve, in case it is subjected to an excessive pressure from the cylinder, as in priming. A flat spring across the back maintains the position of the valve-casting when there is no steam-pressure.

In regard to strength and safety, it is hardly necessary to say that very high-speed engines should be carefully designed, especially on the piston line; and with this in view all the parts in tension in this engine have been made after the fashion of test-pieces, larger in the fastenings than in the body of the rods, by the difference inversely of the limit of elasticity and ultimate strength of the material, so as to be practically unbreakable. The ultimate strength is fixed at ten times the heaviest working load. The large end bolts, tested to destruction, elongated 1½ inch in 4 inches, and as the sections of the piston line are maintained uniform throughout, by the same rule it would stretch about 1 foot before parting. The flywheels are of pressed steel plate, the whole making a perfectly safe construction at any speed.

In conclusion, it may be said that the great usefulness and economy of very high speeds in steam-engines, especially for such

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purposes as electric lighting, is now generally admitted, and the reasons why such speeds are limited in the various types in use are well known. The chief of these may be classified under the headings of heat, knock and wear, and at extreme rates of revolution inertia may be added. In fact, it would appear that inertia must be the eventual limiting cause, if the first three can be overcome, and as the inertia of the double-acting type can be only half that of the single-acting, it follows that the double-acting engine must outstrip its rival. The chief accomplishment of the automatic adjustable and expansive bearing is that it enables the double-acting engine to maintain in a reliable manner the high rates of revolution which can be obtained by its general principles.

It is abundantly clear from protracted trials that engines with a 7-inch stroke can be made to run in a perfectly reliable manner at 600 revolutions per minute, and to indicate 100 HP. at that speed with a single cylinder, without resorting to extraordinary proportions of crank and bearings.

The Paper is accompanied by nineteen drawings, from which Plate 1 and the Figure in the text have been prepared.

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Discussion.

Mr. W. H. PREECE, C.B., President, said it was his first duty to propose a vote of thanks to the Author for the care with which he had prepared the Paper, and especially for the trouble he had taken in making such admirable diagrams. The subject was an exceedingly interesting one to all the members, but especially to those who were engaged in the electrical industry. He thought he ought to point out to the Author that while engine-makers were striving to perfect the high-speed engines, the electrician was improving his dynamos and motors so that they worked now at very much lower speeds than at the time when the high-speed engine was introduced. He did not think the nature of the liquid used in the ram was mentioned in the Paper. Mr. Preece.

Mr. DALES said oil was employed for the sake of convenience, but water or any other liquid would act equally well, if it did not corrode the parts. No difficulties had been experienced in regard to the compressibility of the liquid and the leakages which took place in working. With the proportions which were provided, the compressibility of the liquid gave a clearance on the journal of about $\frac{3}{4000}$ inch; whilst the leakages, by calculation based upon the quantity expended in a given number of strokes, amounted to no more than what would be equal to a clearance on the journal of $\frac{1}{360.000}$ inch per stroke. Mr. Dales.

Mr. HENRY DAVEY scarcely felt competent to criticize the Paper, for considerable experience in the actual use of the contrivance described was required before an opinion could be expressed. He complimented the Author on the ingenuity displayed in the design. He noticed that all the bearings were provided with hand adjustment, and he gathered from the Paper that the experiments with reference to the material and the peculiar form of the bearing-brasses were carried on simultaneously with the experiments with the peculiar kind of connecting-rod and shaft-bearing. He should like to ask if the success the Author had obtained arose entirely from the peculiar construction of the automatic adjustment of the bearings themselves. When there was a hand adjustment as well as an automatic adjustment, it was quite possible that the engineer in charge would tighten up, whenever it became necessary, by hand. Mr. Davey.

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Mr. Davey. Possibly the Author, in his experiments, had left the engine entirely free to the automatic arrangement by drawing back the hand adjustment, giving a large clearance, which would cause very great damage to the engine if the automatic arrangement failed. He should like to know whether such an experiment was made, because it was obvious that if the hand adjustment was close up, it was difficult to say how perfect the automatic adjustment might be. He was struck by the remark made by the President, that electricians were working in the opposite direction; that had always occurred to him as the proper course as regarded speed of rotation. Why not make the dynamos run more slowly, and then there would not be the necessity for engines of such high speeds? Because it was evident from the great trouble the Author had taken to make his quick-revolution engine perfect that it was not an easy matter. He thought dynamos were now made of sufficient size to make it unnecessary to employ such high speeds as those mentioned by the Author.

Mr. Bryan Donkin. Mr. BRYAN DONKIN complimented the Author on the admirable arrangements he had devised for doing away with knock, for lubricating in a very efficient manner, and for minimizing the movement of the parts. But he thought the engine could hardly be said to be of the high-speed type; it would be more correct to call it a quick-revolution double-acting engine. The piston-speed was not high, only about 600 feet or 700 feet per minute; but certainly it was a quick-revolution engine. He was disappointed that the Author had given no indicator diagrams. There were no tests mentioned, and the consumption of feed-water, or, better still, the thermal units per HP. and B.HP. per hour were not noted. But the Paper itself was extremely interesting, and perhaps the Author would be able to furnish this information, and some actual results of its practical work with a dynamo. The question of balancing also had not been touched upon; he would like to know particulars of these arrangements, and also the percentage of clearance, particularly the clearance-surfaces at each end of the cylinder.

Mr. Patchell Mr. W. H. PATCHELL noticed that the Author stated that engines could not be run at the high speeds mentioned, but he had been running, for nearly 2½ years, double-acting engines of 10-inch stroke at 350 revolutions per minute. Owing to the strike and other causes, he had been obliged to run some of the engines for rather more than 2 years without opening them. They were forced-lubrication engines, and, owing to Messrs. Belliss' system,

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there was practically no wear. The Author mentioned clearance as $\frac{1}{500}$ inch. He had ascertained the clearance of his engines, and he found the ordinary clearance was between 0·01 inch and 0·015 inch, whereas the Author fixed the limit at 0·002 inch. He would not say those engines could not be heard when running; they could if one stood close beside them. They had three cranks, and practically no vibration was felt on the platforms round the cylinders. Dr. Kennedy had seen the engines running and he thought he hardly believed, until he heard, how little noise they made. There had been various ways of overcoming the knock in an engine. One had been brought to him some time ago—a spring connecting rod, he thought. The Author of that method had a 30-HP. engine running in the West of England, and said he could not hear it running when standing with his back to it. He was afraid of anything like that, because the man in charge might forget to stop it. With regard to governors, that described by the Author was a very ingenious one. He did not think the Author was very clear in the remark he made that there were not many engines governed to 5 per cent. He thought he meant 5 per cent. variation from no load to full load, not 5 per cent. for a small variation in load. It seemed a large amount, but when actual tests were regarded it was very near the mark. Considerably better had been accomplished; tests of the Waterloo and City engines had shown less than 1½ per cent. from no load to full load.[1] That was with forced-lubrication and throttle-governing. He hoped the Author would give more details about the expense of 5 per cent. variation, because he did not follow his meaning. The only interpretation he could think of was that the Author thought an engine running near full load and not able to work more than full load worked with 5 per cent. waste all the time, as allowance had to be made for variation if more load came on. With regard to the slide-valve being made to act as a relief-valve, with an engine working, as the Author's appeared to be, with very little clearance, and running at such high speeds, he knew that very good relief-valves would be wanted. He should like to know, with Mr. Donkin, whether any tests had been taken of the engine, especially after it had been working some time, because he was very dubious as to whether that arrangement remained steamtight. In an engine such as that shown, there would be very great danger of leakage right away to the exhaust. The

Mr. Patchell.

[1] Proceedings of the Institution of Mechanical Engineers, vol. 1897, p. 256.

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Mr. Patchell. Author at the end of the Paper gave the power of one of the engines, and it was a pity the results of the tests were not fuller. He said that engines with a 7-inch stroke could be made to run in a perfectly reliable manner at 600 revolutions a minute. Practically no one in the electrical world was now interested in a 100-HP. engine, for engineers naturally thought of three of such lines on one crank-shaft; but a 300-HP. engine would not be required at anything like 600 revolutions a minute, and the dynamo makers would have some difficulty in making a dynamo of that size to run at that speed. He was rather struck, on looking into the sizes of some large machines, with the fact that dynamo makers could not build them to run as fast as the high-speed engine people could now make engines to run at; so that engine makers had to come down to meet the dynamo makers. He did not understand how the continuous lubrication was kept up. If he understood Fig. 2, the Author used the top, round about the cap, as an oil-well, and the valve drew it in at every stroke. But how was that arranged for on the connecting-rod?

Mr. Stromeyer. Mr. J. P. E. C. STROMEYER understood that the action of the adjustable bearings was that as the speed increased, or as the knock came on the engine, oil was pumped into the piston and pressed the brasses closer together than they would be if adjusted to run at a low speed. He did not suggest that the connecting-rod was intended for marine engines; but supposing it were applied to that type, and the engine were to race, increasing from 60 revolutions up to 200 or 300 revolutions, then the pumping action would force the piston down on to the brasses, and as soon as the engine went slow again the brasses would be so tightly jammed that he was afraid they would seize on the shaft. Regarding it again from a marine engineer's point of view, the connecting-rod, though very ingenious, seemed so excessively heavy that the side oscillation would have a bad effect on the brasses, especially as there was no brass at the side of the crank-pin. There was only a bearing at the top and the bottom, and with a side-jerk motion he would expect the shaft to wedge itself. He did not see that the arrangement intended for a relief-valve could relieve the back-pressure at all, or very little. The water would have to get between the joint—it was simply a plate with a joint—and he did not quite see that the plate would be forced off.

Mr. Druitt Halpin. Mr. DRUITT HALPIN noticed that the Author referred to variations in governing described in different parts of his Paper, his figures being 4 per cent. and 5 per cent. A Paper had been read

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at the Institution many years ago by the late Mr. Willans in connection with governing, and in the discussion Moscrop diagrams of automatic governing registrations were given of a large electric-light Corliss engine, with a Knowle's double governor.[1] As was usual in those days the lights were shut off suddenly at twelve o'clock when half the load went off by pulling out a switch. It was not possible to trace from the Moscrop diagram where that took place. In fact, the maximum variation shown above and below was $\frac{1}{8}$ of 1 per cent. of the total—$\frac{1}{3}$ per cent. above and below the mean line. Mr. Druitt Halpin.

Mr. W. W. BEAUMONT remarked that bearings of connecting-rods which had a hydraulic cylinder, a pump, a powerful spring, and other arrangements, hardly commended themselves if they were introduced into an engine with the object of running a double-acting engine at a very high speed. If high-speed engines were required more and more every day, it might be desirable to introduce great refinements; but experience having shown how undesirable in many respects very high speeds were, every effort was being made to render them unnecessary, and they were no doubt becoming more and more so every day. With regard to the inertia effect, he was afraid that it could hardly be thought the Author had made any desirable advance when he put a connecting-rod of that kind into an engine in order to be able to run at a somewhat higher speed than others were running without such an arrangement. With regard to the bearings, he thought that with the sides of the bearings cleared away it would be found tolerably easy to keep the bearings of a well-made engine cool. At all events, the difficulties mentioned by the Author ought not to arise to such an extent as to make so complicated an arrangement of connecting-rods and bearings necessary. He could hardly understand the Author's remark: "The expansion of the source of heat overtakes that of the radiating parts." With regard to governing, it was at first strange to see that a governor which reduced the variation of speed below 5 per cent. would possibly save the whole of the coal bill of the engine which was governed by it; but it appeared somewhat more easy to understand it when it was seen that the coal bill was only $2\frac{1}{2}$ per cent. of the wages item. He understood that the variation of speed being 5 per cent. below and above the mean, $2\frac{1}{2}$ per cent. of the time that the engine was running only would be lost at a lower rate of doing work. That being the case $2\frac{1}{2}$ per cent. of the wages Mr. Beaumont.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 198.

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Mr. Beaumont. item would be saved—2½ per cent. being the coal bill. But the Author hardly made it clear that the 5 per cent. would be saved by the governing. If that were so, the governing would be of very much greater value than was placed upon it, even for the most favourable electrical purposes, because the gain would be very considerable. The engine was running at a speed 2½ per cent. above and 2½ per cent. below the mean. That was obvious, because the Author said the term variation was applied to the total range of speed, and not a deviation from the normal. But if that was the case it would appear that the machinery in the large woollen mills would be sometimes running a little higher, 2½ per cent. higher in speed and sometimes 2½ per cent. lower, so that it was not quite clear that the whole of the coal bill was to be saved. He was glad to know of a governor which could achieve such exceedingly close governing.

Mr. Harris. Mr. GRAHAM HARRIS was fairly baffled by the statement to which Mr. Beaumont had referred on pages 95 and 96. He presumed the Author understood it, but he did not. Since hearing Mr. Beaumont speak, he presumed that gentleman understood it, but he (Mr. Harris) understood it even less than before. If some further information might be afforded he would be much obliged.

Sir Frederick Bramwell. Sir FREDERICK BRAMWELL, Bart., had in 1854 made an engine to work directly a circular saw for sawing iron. It ran at a speed between 600 revolutions and 800 revolutions per minute. It was a trunk-engine, with the top side always in connection with the boiler, and the bottom side alternately in connection with the boiler and with the exhaust. The valve was D-shaped in section, but in plan it was an entire circle, running the whole way round the cylinder, cut at one place, and capable of being adjusted to the exact diameter. It floated upon the cylinder, and did not require any back-plate, or anything of that kind, and was absolutely frictionless. That engine ran between 600 revolutions and 800 revolutions per minute with perfect quietness. Then 25 years ago he had experimented with one of Thornycroft's very early quick launches, the "Miranda." He read a Paper [1] on this boat, from which it would be seen that the engines ran 600 revolutions per minute. There was no knocking or trouble of any kind or description, and it had not any of the very ingenious, but somewhat complicated arrangements described by the Author.

[1] Transactions of the Institution of Naval Architects, vol. xiii. p. 269.

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Mr. W. W. MARRINER said it was impossible not to be struck with the very clever and ingenious method the Author had described of overcoming the trouble he had found with his fast-running engines, but his experience was not quite similar with regard to the clearance or knock in brasses and bearings. In some small fan-engines that were running at 1,000 revolutions per minute, it was found impossible to run them successfully unless they had a $\frac{1}{32}$-inch clearance in the connecting-rod brasses. In some larger fan-engines, running about 400 revolutions, the clearance was about $\frac{1}{64}$ inch, and the same applied to some larger torpedo-boat engines which ran 400 revolutions and indicated about 2,000 HP. The whole question of running engines at high speeds was one of lubrication, and any attempt to run engines successfully at high speeds must be in the direction of forced lubrication similar to the means adopted by Messrs. Belliss. He thought that if the Author in his engine had put the extra weight into increasing the bearings, and adopting improved methods of lubrication, he would have obtained even better results than he had. In the high-speed engine there was also another point, and that was, if the number of working parts were increased, the liability of the engine to a breakdown was much greater. Mr. Marriner.

Dr. A. B. W. KENNEDY was sorry the Author did not state at the commencement of his Paper—as was certain he knew quite well—in bringing forward two novelties in the construction of high-speed engines, that, after all, those novelties were only one pair of methods out of many others which were at work at the present moment, for rendering high-speed double-acting engines practically successful. He did not wish to join in some of the unfavourable comments which had been made on the Author's plan. It was quite true that the arrangement with the hydraulic cylinder for keeping the bearings in contact looked more or less complicated, yet he thought it was perhaps a little cheap criticism to lay great stress upon this until it was seen in existence, and experience was obtained of how it was going to work. If it was, as he thought very probable, an exceedingly good way of at the same time preventing knock and allowing of forced lubrication, then he was content to believe that the little additional complication might be got over; at any rate it was a matter for practice to settle. In the matter of the governor, he was in the same position as Mr. Harris and other speakers; he thought there must have been a mistake. He did not see how the governor could possibly effect economy in steam, unless it was to be interpreted Dr. Kennedy.

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Dr. Kennedy. as suggested by Mr. Patchell. Quite on the contrary, an absolute alteration of speed might be very economical, because if an engine had to work at very varying loads at different times, it was better to work it slower when working at lower speeds, in order that so much work might not be expended in engine friction, the engine friction being more or less constant per revolution. Therefore, if an engine was run at full load at 400 revolutions and at light loads run only at 300 revolutions, the efficiency at the lower loads could be made proportionally higher and the economy of the engine correspondingly improved. He had specified engines to be made so that they would be employed in that manner, but he never found that the drivers would so run them, and he had therefore discarded the clause in his specifications, but it was undoubtedly to a certain extent a source of economy. In reference to other systems which were in use, he could fully endorse what Mr. Patchell and others had said as to the working of the Belliss double-acting engines. They made practically no noise, they ran at extremely high speeds, and their lubrication was absolutely perfect. With regard to their governing, he could not pretend that he knew anything that attained the governing Mr. Halpin had mentioned; but in the engines which were used on the Waterloo and City Railway he had seen the whole load—when the engines were driving a dynamo working at full load on resistance—thrown off suddenly and again thrown on, and he did not think that a casual observer looking at a couple of ordinary glow-lamps in the circuit would be able to tell that anything had happened. In throwing off load especially he could hardly tell that anything had happened, and that was, after all, governing closer than was ordinarily wanted. The governing was of the throttle-valve type, and was made specially close in this case simply because it was wished to run the lights in the trains off the same circuits as the motors. If any of the members present travelled by that most luxurious and modern method of travel, the Waterloo and City Railway, he had no doubt they could read quite comfortably all through the tunnels, and did not find that the lights varied sensibly, although the power upon the motors was varying enormously from minute to minute.

Mr. Dales. Mr. DALES, in reply to the Discussion, expressed his obligation for the manner in which the Paper had been received. It had been his intention to confine it to an investigation of the mechanical action only of steam-engines, as a suitable preliminary to further enquiries as to the possibilities of generally increased

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economies which might accrue from very high rates of rotation, considered both relatively and actually, that was to say, from increasing the speeds of engines of any size, both large and small. A method was first necessary of making relatively high rates of rotation practicable, and that had been accomplished. The second condition necessary was running very closely to any normal speed, and this had also been accomplished to a point which appeared to fulfil all practical requirements, the possible running being to within 1 per cent. This amount was the extreme oscillation of speed which could be brought about by absorbing the full power of the engine by a brake applied to the fly-wheel, and by the instant release of such brake, leaving nothing for the engine to drive but its own friction. This was the most extreme variation of work which can be put on an engine, and much greater than any which could be effected by manipulating a dynamo. The variation was not a deviation from the normal speed, but the total difference of speed which was brought about. In most ordinary cases considerable deviations were brought about not by a change of work but by a regular oscillation of speed in the engines, which was caused by the friction, inertia and other defects of the governors and expansion-gears applied, and which, in performing their functions, were always either behind the requirements of the engine or over-acting, and there was a rise and fall of the speed indicator line which was due to change of work, in addition to the broad mark of friction deviation made by the pencil. This regular oscillation of the engine speed might be easily observed by watching the action of a common governor and throttle-valve. The balls ran a few revolutions in a low position; they then rose and ran a few revolutions in a higher position; then the reverse action took place and went on indefinitely without any change of work having taken place. The same thing occurred in a greater or less degree with any governor; but in one which would run an engine to a total variation of 1 per cent. it was imperceptible and, for practical purposes, did not exist. To prevent racing, the setting or adjustment of the governor could not be nearer than about four times the friction variation of the governor. Where so fine governing was required the friction and inertia must be so very low that only correct principles of design could accomplish the desired end. If, however, such correct principles were applied fine governing was just as easily obtained as any other, and the governing element in engines so provided was a great deal less trouble than ordinarily. The application of the methods referred to in the Paper had been made both on a test engine for extreme

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Mr. Dales. speed and also in engines doing regular work, at unusually high rates of rotation, during 4 years, and the results had shown that neither extreme speed nor time had had any detrimental effect upon the appliances, and that they were in fact amongst the most permanent parts of the engines, and which for running purposes were practically always perfect in their mechanical action. The parts which in the hydraulic adjustments were extra to ordinary fittings were all practically fixed, and did not partake of the nature of mechanism as ordinarily understood, and they did not require skilled labour for the maintenance of their efficiency. The packings of the rams would last 12 months or more, and they could be renewed by any ordinary engine-tenter in a few minutes. The men who had had charge of the engines fitted in the manner described (and which were all of one size, indicating up to 85 HP. on 80 lbs. to 90 lbs. steam, and running up to 480 revolutions per minute), had performed the combined duties of fireman, shaft-oiler, engine-tenter, and, in one case, electrician, and received 25*s.* per week as wages, where they had only one engine to attend to. The speed trials made with single-acting engines by the late Mr. Willans showed conclusively that a very large saving in cylinder economies was effected by running at comparatively high rates, and it was likely that, with similar clearances and steam distribution, at least equal steam economies might be obtained from double-acting engines, in addition to some of the undoubted mechanical advantages of the double-acting type, not the least important being their very much smaller engine friction, which amounted to not more than 5 per cent. of the full load, whilst the friction of single-acting engines was about double that amount. Although it was not possible in double-acting engines to have the true Cornish steam cycle in the high-pressure cylinder, a close approximation to that might be obtained, and the double weight of steam which passed through the cylinder in a given time there was little doubt reduced the proportion of the cylinder losses; so that, taking the cylinder losses and friction together, there was probably a balance of engine efficiency left in favour of the double-acting type. He thought it was agreed that the double-acting type was mechanically superior to the single-acting. In regard to the ordinary rates of revolution in steam-engines of the double-acting type fitted with fixed bearings the extreme rates in current practice were 500 revolutions at 100 HP. and 380 revolutions at 350 HP.; these were respectively two- and three-crank engines; the average practice was very much lower. The speed test with the 6-inch-stroke engine had shown that no such speed

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as 600 revolutions could be maintained for any time with a fixed bearing. A test for the establishment of this point was easily made by screwing down the hydraulic cylinder-top until the bearing was fixed and solid without putting any nip on the bearing. This had been done experimentally on several occasions and the bearing speedily heated whatever the lubrication. The bearing had also been run with sufficient knock to prevent its seizing, but at such a speed as 600 revolutions the hammer of the journal both generated heat and drove out the lubricant, and the bearing became hot. The results of these speed trials had sufficiently established that there was a very large difference in the possible rates of revolution of fixed and expansible bearings; and, also, that extreme speeds such as had been attained were only practicable with close-up bearings of some such design as those described. Experimentally a speed of over 800 revolutions per minute had been attained by 8-inch-stroke engines, but it was found that crank-necks, 5 inches by 3½ inches, such as were provided, were insufficient to stand the speed, and they gradually warmed. Presumably the necks were too short. All the stationary bearings, however, stood the speed perfectly well. Longer crank-necks provided on the 6-inch engine remained perfectly cool at 600 revolutions; in fact, the whole of the trials had shown that for very high speeds very long crank-necks were necessary. The difficulties of high speed increased very much more rapidly than the rate of revolution. The friction item due to the revolution of the shaft and the viscosity of the lubricant increased directly as the speed; but both the inertia of the piston-line and the centrifugal force generated on the crank-journal increased as the square of the speed. At some of the trial speeds the centrifugal force on the crank-neck was about eighty times the weight of the material; it was thus easy to see how the lubricant would be thrown off the journal. As the friction increased directly as the speed and the inertia as the square, the limit of speed for any given clearance with fixed bearings would be pretty clearly defined, and when the extreme maintainable rate had been reached it was very difficult to increase it by ever so little. He had experienced this in ordinary practice, especially in high-speed ordinary practice. With 16-inch stroke engines having fixed bearings he had been able to run 225 revolutions with tolerable certainty under certain circumstances; but it was not easy to maintain 250 revolutions with an adjustment which was satisfactory in regard to knock. It did not appear that a large quantity of lubricant was of special value at high rates of

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Mr. Dales. revolution, the great centrifugal force generated throwing off any bulk of oil fed to the wearing-surfaces, only such as clung to the surface of the metal being actually useful for lubrication. All the results referred to had been obtained without forced lubrication, an ordinary drop-feed having been used. The quantity of oil required for the 85-HP. engines was about 1 pint per working day, which cost 1½*d.* (1*s.* per gallon). Certainty of action in the lubricating arrangements was of more importance than either quantity or quality of the lubricant. The governor shown on the diagram had thoroughly proved the soundness of the principles on which it was designed and had developed no weaknesses, but, on the contrary, had shown that it was as permanent as any other part of the engine, and also that, as the sliding parts became easy by wear, the quality of the governing improved. The governor proper had only two moving parts, or, rather, one which was duplicated, and there was absolutely nothing to get out of order. If a spring broke it simply dropped the speed of the engine so very slightly as to make no perceptible difference. Such a thing had occurred only once with a spring made by strange men during the strike. The governor could be regulated from the switchboard when running by applying a small motor in the wheel for screwing up the load-springs, the necessary current being carried by two contact-rings on the outer surface of the wheel and suitable brushes. It should be noted, however, that any centrifugal governor which would work throughout its entire range with a variation of speed of only 1 per cent. could not be screwed up more than about 2 per cent. or racing would occur, and that if the speed were much lowered by unscrewing the springs the fineness of the governing would be spoiled. There was very little margin either one way or the other. Referring to the action of the governor upon the expansion-valve motion, the eccentric-rod, valve, and parts were driven by the engine through the governor, and the force required for this formed a permanent load on the centrifugal parts. Experiments made for the purpose of ascertaining this quantity without the load-springs showed that a speed of about 100 revolutions per minute was required to balance the driving-force. The normal speed of the same engine was 450 revolutions, so that the squares of these two speeds would give the difference between the driving power of the valve motion and the total centrifugal force of the governor. Worked out this was 1 to 20¼, say the driving power was 5 per cent., and it would be seen further that the length of the governor-slide was to its width about 2½ to 1, which would cause a side friction of the guide-rods

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due to 2 per cent. of the total centrifugal force. The actual friction would then be, if the rods were dry, 10 per cent. of 2 per cent. of the total centrifugal force, or $\frac{1}{5}$ per cent. of that quantity. This would partly explain the comparative absence of friction in the arrangement. In regard to the necessity for high speeds it was always advisable to derive the highest service out of any given appliance. High speed, if it gave commercially increased value, was not any matter of choice, but a necessity. No user could afford to run his engine at any slower rate than the fastest which could be maintained. He could not agree that engines used for electric light purposes had been ahead of the dynamos driven in the matter of speed. A 100-kilowatt alternator ran at 500 revolutions, and required about 170 HP. indicated at the engine. He knew of no single engine or single pair of engines which would do this direct driving. A 200-kilowatt dynamo was easily practicable at 500 revolutions, and a 300-kilowatt machine was given by an eminent authority as running at 400 revolutions. This latter would require nearly 500 HP. He was acquainted with recently-built engines by one of the best firms, which indicated 500 HP., with three cranks and three tandem compound cylinders, and they did not run at nearly that speed. He had received a letter from an eminent builder of dynamos, in which he stated, "the question is one largely of design. I don't think it impossible to design a 300-HP. dynamo to run at 600 revolutions. Mr. Parsons runs his machines at 3,000 revolutions; but, nevertheless, there are few if any dynamo-builders who have patterns, &c., for such a machine. The tendency has undoubtedly been of late to bring down the speed of dynamos, partly because the engines available have a slower rate, but also because the multipolar design is coming to the front with its largely-increased diameter of armature. The multipolar type of dynamo is necessary for large powers because (1) there is a great saving of weight in the magnets; (2) the armature reaction in two-pole dynamos of large output is too great; (3) the introduction of carbon brushes necessitates larger commutators with a number of brushes in parallel at several points round the commutators." Both dynamo- and engine-builders preferred to make large machines, but the principle of making more expensive appliances than were really necessary for any given purpose was obviously unsound, and both contractors and consumers would always buy those appliances which were best for their cost. In regard to uniformity of rate of rotation, it had been found that with first-class governing, say $1\frac{1}{2}$ per cent. total variation of

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Mr. Dales. speed, a two-pole dynamo might be driven by belting on glow-lamps by an engine speed of 170 pulsations per minute (85 revolutions double-acting) without any perceptible variation of the intensity of the lights, and it was clear that the better the governing the less the necessity for a multiplication of cranks and cylinders became. In the test case above mentioned the maximum pulsation possible was 12½ per cent. per stroke, that was to say, the speed of the engine running light was, by full steam and latest cut-off, accelerated 12½ per cent. toward the full speed per stroke. With a single-cylinder double-acting engine running 450 revolutions per minute, perfect driving could be obtained with very light fly-wheels, with wheels made from pressed steel plate (like boiler ends) for the sake of safety. The maximum pulsation possible in this engine with 90 lbs. steam is 4½ per cent., or nearly three times better than what was proved to be good enough. Carrying this point further, the maximum pulsation per stroke possible in the 6-inch stroke 600-revolution engine was only 1⅞ per cent., or six and two-third times better than what was good enough and sufficient in turning quality for the very best class of work. As regards uniformity of torque, no appreciable betterment could be obtained by the employment of three-crank engines over a single piston line at high rate of rotation when it was provided with first-class governing; and perfect balancing, with consequent absence of vibration, could only be had by placing one large cylinder on one centre between two small ones of an equal weight of piston line and cranks collectively on the opposite centre. This arrangement would appear to be the best possible, and could be either compound or triple. Messrs. Braithwaite, of Elstree, had in hand a twin-cylinder compound engine to indicate 300 HP. at 450 revolutions per minute with one pair of cylinders of 21¼ inches and 15¼ inches by 10 inches stroke on 120 lbs. steam condensing, and it was intended with this type to make exhaustive trials of the steam results which might be obtained by different speeds in double-acting engines, and also of the relative merits of cut-off and throttle-valve arrangements as regards both steam economy under varying loads and the possible governing qualities of each method. The trials would be made with the same valves and valve motion and the same governor, the design lending itself in such a manner for the purpose that it was expected the results would be conclusive and that the data obtained would be valuable. The total cylinder clearances in this engine amounted to 6½ per cent., of which 2½ per cent. consists of ¼-inch piston clearance at the cylinder

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end, leaving less than 4 per cent. for the port and piston-valve clearances. The latter were the smallest clearances possible with a side port and piston-valve to give $\frac{1}{24}$ and $\frac{1}{17}$ of the cylinder area respectively for steam and exhaust thoroughfares, and were about the same as Willans' single-acting engine with central valve. This engine was being built on a guarantee to run 140 hours a week regularly without stopping, that was, from 2 A.M. on Monday morning to 10 P.M. on Saturday night. It was fitted with both the hydraulic adjustments and the governor as shown on the diagram. In regard to the commercial value of high speed, it had been found that at a sale price of about £2 10*s.* per indicated HP. on full load and normal speed, engines of the highest class could be provided in sizes over 200 HP. and down to 100 HP. at about £3, whilst the difference in cost of dynamos running 350 and 450 at 200 HP. output would be about 12 per cent. to 15 per cent. Long-stroke engines of the power named would cost about twice as much as stated, with a proportionate outlay for buildings. In making the trials of the bearings every care was taken that the adjustable plugs were properly set with sufficient clearance to prevent the bearings seizing, and for an increase of temperature which would melt out the white metal. The object of the plugs was to make the packing adjustments of the rams more convenient than if any exact quantity of packing was required; and also they were for the purpose of following up the wear of the brasses, so that in case of any breakdown which might release the liquid taking place no destructive knock in the bearings could occur. In one instance of an engine fitted as described, which was now working close to the sea-shore, and the bearings of which were supplied with very fine sand by every breeze, the wear on the crank-pin, gudgeon, and the four brasses, eight surfaces in all, had caused a clearance of $\frac{3}{8}$ inch behind the ram in a space of 18 months, but the engine worked perfectly well. A re-adjustment was made by taking out washers under the big end cap which were provided for the purpose. In such a place decent running in an engine fitted with fixed bearings could only have been secured by letting the four brasses up about once a week, which would have cost in time a very great deal more than the total cost of all the adjustments together. The piston-speed mentioned was high for a 6-inch stroke engine, being 600 feet or 700 feet per minute, the latter being about the rate of some of the highest speed long-stroke engines, and as it was always easier to get piston-speed by stroke than by rate of revolution, he thought the piston-speed attained was perhaps an achievement. The methods of attaining speed

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Mr. Dales. and economy were such as could be applied to any type or design of double-acting engine, and the steam economies would be according to such type or design. Very satisfactory work on dynamos had been done by engines fitted in this manner up to 50 kilowatts output, the extreme steadiness of the speed being much appreciated by the electricians. The cranks and connecting-rod end were balanced fore and aft; some of the later engines were somewhat overbalanced in this direction to partially balance the piston-line. These seemed to run best. A 10-inch stroke fitted with close-up adjustments as described would run comfortably at 450 revolutions per minute, and the difference in the inertia of the piston-line between 350 revolutions and 450 revolutions would be as 12·25 : 20·25, or roughly as 3 to 5, and with the $\frac{15}{1000}$-inch clearance mentioned by Mr. Patchell there would be a very great knock at 450 revolutions. In referring to quiet running, he meant no knock whatever. He thought the Paper was quite clear on the percentages of governing. It stated that average governing was not nearer or so near as 7 per cent., and that there were very few engines indeed which run so near as 5 per cent. total variation, and that it was evident the best quality of governing, 1 per cent., would produce on the average 4 per cent. more work, which would in most cases pay for the whole of the coal bill, and that therefore good governing was of greater importance than small steam economies taken by themselves. The saving was really more than the 4 per cent., because the engines run slow on the heaviest load, so that it would not be stating too much to say that the saving, or rather extra saving, would be 6 per cent. He did not know of any method for avoiding knock other than the one submitted, which both took up wear and allowed for expansion. Taking up wear alone could be done in many simple ways. There was no slide-valve as referred to by Mr. Patchell, but a valve-case which was kept in position against a scraped port face by the pressure of the steam in the chest, and which in case of priming was forced off the port face in the same way as an ordinary slide-valve. This joint had kept good in a remarkable way. It was thought when it was first applied that it might require re-bedding every few years, but in one engine after 3½ years' work the joint was found to be perfectly good, the cylinder oil having entirely preserved it from corrosion. There never was any intention of making 300-HP. engines to run 600 revolutions, although that did not appear to be at all impracticable. Dynamo makers were recently asking for engines

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to run 600 revolutions and indicate 100 HP. The engine illus- Mr. Dales.
trated was made solely to demonstrate the efficiency of the hydraulic adjustment and its independence of speed. The arrangement of bearing shown was not intended as a method of forced lubrication; the liquid in the hydraulic cylinder was intended to act as a stop or filling to keep the brass in position without pressure. The lubrication was by the ordinary drop feed. The leakages (not the lubrication) from the connecting-rod cylinder were supplied from a spring piston reservoir, the charge in which would last, when the packings were good, up to 2 months in regular work. Forced lubrication was not necessary to get a double-acting engine fitted as shown to run any speed. Oil was not pumped into the cylinders, but was drawn in after the manner of the suction-valve of an ordinary pump, and it then remained as a stop. The arrangements were eminently suitable to marine engine-work, and no difficulties could arise even if the valve were to stick, or any other unlikely thing to happen, as the hydraulic cylinder ends would be adjusted to the same clearance as ordinarily necessary to allow the engines to work, but by the action of the adjustment the usual thud of all the bearings would be stopped. For very fast craft with high rates of revolution much better running than ordinary could be obtained. In regard to racing, such a governor would prevent it if applied to the stop-valve. No more severe test could be applied than that of the brake referred to. In regard to the weight of the hydraulic connecting-rod as it was usually constructed in small sizes, the weight of the piston-line was increased from 5 per cent. to 10 per cent. In large sizes the weight was about the same as an ordinary arrangement. This arose from the high compressive strength of the cylinder. The tension bolts were about the same in weight as the big end and small end bolts combined ordinarily. No such wedge action as Mr. Stromeyer mentioned took place by reason of the easing of the brasses, the inclines being 1 in 1. Also the adjustment held the upper and lower brasses in close contact. He thought Mr. Druitt Halpin held an erroneous idea of the figures quoted in regard to governing. In the case he quoted it was not possible to trace from the Moscrop what took place. He doubted that the centrifugal governors which he had seen used in these machines some years ago would change position with much less than a 2 per cent. variation from the normal, or a total of 4 per cent. He thought they had a regular "race" of their own. Also their driving-bands, as he had seen some, were not at all

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Mr. Dales. calculated to transmit the exact motion of the engine to the pencil. He had run an engine, fitted as described in the Paper, without oil until the white metal was melted out and thrown all over the engine-house, but the engine did not either knock or pull up. By "the expansion of the source of heat overtakes that of the radiating parts," he meant that when a bearing began to heat, the journal and brasses expanded quicker than the outer parts of the bearing, for the reason that they were the source of heat and hotter than the outer casing. Mr. Beaumont had formed a clear view of how the coal bill might be saved by good governing. It would perhaps be more correct to say that sufficient extra money could be earned to pay for it. In all manufacturing processes there was a limit of speed which the material operated upon would stand without damage, and, consequently, engines which varied widely had to be speeded lower than they should, so that they might not overrun such limit, and if the highest rate was, say, 100 revolutions, 1 per cent. governing would vary from 99 revolutions to 100 revolutions, giving 99½ revolutions as the average. If, however, a governor varied 7 per cent. (which was under the mark rather than over) the speed would be from 93 revolutions to 100 revolutions, and the average 96½ revolutions, or a loss of 3½ per cent. against a loss of ½ per cent. But the actual loss was really more than the 3½ per cent., because the bulk of the work was done at the lower speed. It might be said that an adjustable governor could be regulated, which was perfectly true, but if the full speed was run with the full load on, and part of the load suddenly dropped off, the engine overran before the governor could be let out again and the damage was done. He had known 400 glow-lamps to be smashed in about 2 seconds by such a thing. It was well known that many engines had to be governed by hand when the full load was on on account of these difficulties. He was sorry to hear that Mr. Graham Harris was fairly baffled, and was afraid he had stated that good governing saved the coal bill instead of earning it. The result would be about the same to the man who had to pay. With reference to the clearances mentioned by Mr. Marriner, he had never been able to run engines quietly with $\frac{1}{32}$ inch of slack. It was possible to run the connecting-rod of an engine pretty quietly, or at any rate with no heavy knock, if the inertia of the piston line and steam-pressure exactly corresponded, with considerable clearances; but an engine seldom ran on work with the conditions so well balanced. Possibly the centrifugal force of the big end of the rod was sufficiently above the effect of

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the steam-pressure to keep the crank-pin in contact with the eye of the rod, whirling round it as it were. But the stationary bearings could not be kept quiet by any such means, and $\frac{1}{32}$-inch clearance would mean ordinarily what would be termed a "steam-hammer knock." In none of the cases mentioned, he supposed, was there any pretension to silent running. He was glad Mr. Marriner corroborated his statement that a clearance which was out of reach of the expansion of heating was inadmissible in ordinary work; and he could assure him that no such speed as 600 to 700 revolutions could be run with a 6-inch stroke with any clearances at all, as the hammer caused the bearings to heat. As regards the possibility of running dynamos on variable loads with constant or very closely approximate constant voltage, without any alteration of the governors of the driving engine whilst running on the work, there appeared no difficulty in arriving at such a desideratum with engines which would run to a total variation of 1 per cent.; seeing that continuous-current dynamos could be made to give constant voltage to within 1 per cent., and can be made to give a higher voltage at the same speed on full load than on light load, if desirable. Assuming that voltage in such dynamos varies directly as the speed for a sufficient range about the normal for the purpose referred to, a fall of speed of 1 per cent. at the engine would give that amount of difference in voltage at the dynamo, and if the voltage at the dynamo fell 1 per cent. for increased resistance on full load, the total fall of voltage would amount to 2 per cent. Now an engine governor adjusted to a 1 per cent. total variation could not be screwed up in speed more than about 2 per cent., or racing would occur, but this amount would about make up for a 2 per cent. combined fall of voltage due to increased load both in engine and dynamo. In the case of an over-compensated dynamo, no fall of voltage would occur even without any alteration of the governor. The risk of overrunning in case of sudden reduction of load could be limited to 2 per cent. in the first case, whilst in the second there would be none in any circumstances. He referred to results obtainable at the dynamo; which would be such as would make no ordinarily perceptible difference in the light, nor would they cause any damage. As a comparison with an engine varying 5 per cent. (a moderate estimate of ordinary governing) there would be in such a case a fall of voltage of 5 per cent. due to the full load on the engine, in case of non-interference with the governor, and a further fall of 1 per cent. voltage, due to the full load on the dynamo, or a total of 6 per cent. loss; while in the case of screwing up the governor the

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Mr. Dales. risk of overrunning would be to the extent of 6 per cent., which would make a very perceptible difference in the light by either the fall or rise of voltage. The governor mentioned in the Paper could be manipulated from the switch-board, by means of a small motor placed in the fly-wheel and suitable contact rings and connections. Variation of voltage due to difference of load was due much more to the bad governing of engines than to the imperfections of dynamos, and with engines running to a 1 per cent. total variation of speed practically constant voltage could be obtained under any variation of load whatever, and ordinarily no alteration of governors whilst running would be necessary. Such results would, in central station work, effect a large saving in the attention ordinarily necessary to preserve approximately constant voltage in the mains, and at the same time increase the output from any given plant. There was a further point in favour of direct driving of dynamos by high-speed engines which was not generally taken into account, namely, the loss of speed on the dynamo by the elasticity of the driving belt or ropes—between light load and full load. The extent to which voltage, and, consequently, useful effect might be lost, was much greater from this cause than at first sight might be supposed. As a case in point, he had one of his engines driving 85 HP., at 480 revolutions per minute, through a 9-inch by $\frac{3}{4}$-inch link belt on to a dynamo running 600 revolutions, which absorbed that amount of power. The belt was put on as tightly as it could be got on, and on light load (about 6 HP.) the belt ran with both sides about the same curve, but when the full load was applied, the length of the slack side became 5 inches greater than the tight side, between 17 feet centres of the pulleys. There would be no stretch on the slack side when running on full load, and there would not only be double the initial stretch on the tight side, but also 5 inches more, and for every 17 feet of belt which went on to the driving pulley, 17 feet 5 inches, plus the original stretch, would come off, and the belt would continually creep the extra length. The mere stretch of the belt in this case diminished the speed of the dynamo 3 per cent., without any fall at the engine being reckoned, and the latter being 1 per cent., made 4 per cent. altogether from these two causes. Added to this the increased resistance of the dynamo of, say 1 per cent., there would be a loss of voltage of 5 per cent., instead of a total of 2 per cent., by direct driving of the same engine and dynamo. The loss by stretch of ropes would probably be greater. In short, it was necessary to carefully watch all the points and causes of loss if close running

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must be made, and it was of little use having one point excellent if the others were bad. To obtain good driving of dynamos by belt or rope, a very large margin of strength must be allowed, and excellent driving could be obtained only by direct coupling. Mr. Dales.

Correspondence.

Professor M. F. GUTERMUTH found it difficult to judge the value and practicability of the design of the Author's engine only by the description and the drawings. He had no doubt the method shown in the Paper avoided knock in the driving parts of high-speed engines as long as they were new, but he could not believe that the complications employed would prove in the long run very satisfactory; and he had the impression that the advantage of smooth running was paid for too dearly by the great disadvantage of too many parts, which would cause in time difficult and costly repairs and shorten essentially its durability. The type of engines constructed by the Author was not fit to be used everywhere, but only where skilful hands would manage them. For high-speed engines the greatest simplicity in the construction of all their parts ought to be observed. The smooth running could be ensured by giving sufficient compression of steam, ample surface and thorough oiling to the bearings, and by using for the latter that accuracy and care of make which the Author required for the whole construction of his complicated driving parts and bearings. As to the governor, it could be said that many similar types existed already which had proved very satisfactory, and which allowed the same small variation of speed of 1 per cent. to 1·5 per cent. between full load and no load. But present experience showed that such steadiness in the speed was not at all suitable for most or all the purposes in which these high-speed engines were used. Prof. Guter-muth.

Professor T. A. HEARSON considered the device described by the Author for eliminating the knock in the bearings of a high-speed engine very ingenious and probably effective, but the result he aimed at was capable of being achieved more simply and probably more effectively by means of forced lubrication. The Author's explanation of the advantages which he claimed for his automatically-adjustable bearing was just that which was wanted for a full appreciation of the very great merits of forced lubrication. His design was for the purpose of providing an adjusting enlargement Prof. Hearson.

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Prof. Hearson. of the bearing to suit the expansion of the journal which took place under ordinary working circumstances due to the heat developed. On the other hand, by means of forced lubrication, thoroughly carried out, rise of temperature and expansion was prevented or delayed until the whole mass of the bearing had time to become uniformly warm. Probably the original purpose in the adoption of forced lubrication was to conveniently get at somewhat inaccessible parts, such as the crank-pin and eccentrics, but with suitable arrangements the results obtained were of much higher value. To be quite successful the joints and bearings must be of uniformly good fit, and, unless a very great pressure was employed in forcing the oil, reversal of pressure in the bearing was requisite. In the double-acting engine the reversal of pressure gave the opportunity for the entrance of the oil alternately to the two sides of the bearing, and with good fit there was not time in a high-speed engine to squeeze out all the interposed film before reversal again took place; therefore the metals practically did not come into contact, and the wear was minute. By repeated use of the same lubricant rise of temperature and expansion resulted. To maintain the accuracy of fit, then, the outer portion of the bearing should be allowed to expand also by being kept warm. This was provided for by enclosing the working parts and preventing the access of cold atmosphere. The enclosing introduced other advantages, viz., that the oil was kept clean and prevented from spilling. It was quite certain that great advantages would follow on the adoption of forced lubrication in all engines which had anything like a high speed, such as yacht engines and those of torpedo-boats and destroyers, the working parts being enclosed. The engineer who carried out the system thoroughly in an express locomotive also would probably score a great success.

Mr. Hudson. Mr. JOHN G. HUDSON remarked that there could be no question as to the reality of the difficulty which the Author had brought forward regarding the adjustment of the principal bearings about a reciprocating engine, so that, on the one hand, the clearance might be small enough to prevent injurious knocking, and, on the other hand, to prevent seizure through the expansion of the steps, should they become overheated. This difficulty was not limited to the lightly-loaded bearings of engines running at an exceptionally high speed of revolution, but was equally pressing in the case of the heavily-loaded and comparatively slow-moving parts of large engines. The form of adjustment adopted by the Author to overcome the difficulty seemed to be admirably adapted to

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secure automatically a correct adjustment, so long as it continued in perfect working order, but the degree of complication involved would, it was feared, involve considerable risk of failure, at least in the hands of all but a very few engine attendants. The allowable limit of complication seemed to be reached in the stationary bearing for the crank-shaft, and to be exceeded in the connecting and eccentric rods. In place of this automatic adjustment, and a moderate supply of lubricant, the alternative method adopted by Messrs. Belliss and others, of allowing sufficient slackness to avoid overheating in case of seizure, and furnishing the bearing with a copious supply of lubricant under pressure to form a cushion between the surfaces and, at the same time, to carry away the heat generated by friction, seemed to secure the practical requirements in a very much simpler and cheaper way, and to be equally suited to allowing the engine to be run at an extreme speed. The Author's experience as to the need of supplying the lubricant to each separate segment of the bearing where fine adjustment was adopted, was of much interest, and he had found the same method to be of great service in the case of difficult bearings, particularly those of crank-shafts carrying heavy fly-wheels, and working in three-part steps. The same remarks applied to the methods adopted by the Author of dispensing with the usual oil grooves, easing off the sides of the steps, and limiting the arc of contact; but he would prefer to ease them off only on the leading-on side, and to make the easing off as gradual as possible, in order, as it were, to lead the lubricant insensibly to the point of maximum pressure. He could not endorse the Author's experience as to the satisfactory working of solid piston-valves, and might quote a recent case in which, after a few months' use, the leakage past the high-pressure valve into the low-pressure cylinder was sufficient to put the engine beyond the control of the governor at light load, although the wear on measurement was found to amount to only $\frac{1}{120}$ inch on the diameter. In the case referred to the valve was no doubt working under conditions tending to rapid wear, the steam being wet; but, even under favourable conditions, this type of valve could not be considered wholly satisfactory, either on the ground of governing or steam economy, and the need of this or some other balanced form of valve was one of the disadvantages attending the use of shaft governors, unless the designer was prepared to make the governor of sufficient size and power to control some tighter class of valve. As regards the design of the shaft governor illustrated, there could be no doubt as to its simplicity, but it was somewhat surprising to learn that

Mr. Hudson.

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Mr. Hudson. springs working on the outside of tubes should have so little friction; also that the inertia of the parts of the governor should be sufficient to prevent any movement of the latter when driving the eccentric and valve, as it was found in the majority of shaft governors that there was a small but constant movement of the parts, which rapidly produced wear of the working surfaces, unless these were made of abnormal dimensions, the exceptions being those in which the parts were so arranged that the thrust was taken on surfaces lying within the angle of repose, such, for example, as the McLaren governor, which was largely used for electric-lighting purposes. The Author's experience of the governing of Corliss engines seemed to have been most unfortunate, good governing being rightly considered one of the most valuable merits of this type of engine, and indeed in many cases the special justification and reason for the use of this class of valve-gear. Instead of the total variation of 9 per cent. between no load and full load experienced by the Author, he had had no difficulty in getting down below 2 per cent. with a governor specially designed for electric-lighting purposes. In this case the governor was of the bent-arm or Proell type, controlling the valve-gears of both the high- and low-pressure cylinders of a compound engine, and this with the utmost steadiness and freedom from the slightest suspicion of hunting. The bearings at the meeting of the upper and lower arms were formed of knife-edges, to provide for the impossibility of lubrication during long runs, but the other bearings were pins of ample diameter, special arrangements being readily made for their lubrication and that of the sliding parts whilst running. Even with a more ordinary type of high-speed governor, actuating the valve-gear of only one cylinder, no difficulty was found in obtaining a very much closer regulation than that stated by the Author.

Prof. Jacobus. Prof. D. S. JACOBUS, of Hoboken, N.J., considered the idea of employing a hydraulic ram for adjusting the brasses of the bearing the way proposed, to be an ingenious solution of the problem of producing a bearing to run at high speeds where the pressure was alternately in one direction and then in the other, and that the utility of the device could be determined only after a number of the engines in which it was used were placed in general service, when time would show whether it was reliable under all conditions and after long periods of running. In regard to the action of the governor, he considered that what might be called the instantaneous variation in the speed of the engine when the load was changed should be considered, as well as the average speed

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per minute. A governor might overcarry, and there might be pulsations in the speed when the load was suddenly changed, which would not be manifested if the number of turns per minute alone were recorded. In the work of Messrs. Ball, Corbett, and Barnum of the Class of 1895 of the Stevens Institute of Technology, as a graduating thesis, the instantaneous variation of speed was determined by employing a vibratory tachometer. This consisted of a bar held at one end and vibrated electrically. At the free end of the bar, or the end which vibrated, there was a screen through which a narrow slot was cut. A second stationary screen with a corresponding slot was placed parallel to and nearly touching the vibrating screen. On looking through the slot in the stationary screen the light entered the eye at intervals corresponding to vibrations of the moving screen. This apparatus was placed in line with the shaft, and a short distance from the fly-wheel of the engine. On viewing the fly-wheel through the slot it appeared to remain stationary provided the vibrations of the bar were made to correspond to the frequency with which the spokes of the fly-wheel passed a given point. If there was a change in the velocity of the fly-wheel it would appear to revolve either forward or backward, when viewed through the slot of the vibrating tachometer, and the amount of this rotation measured the variation of the velocity. The speed of vibration of the bar was adjusted by means of a sliding weight attached to the bar. By this apparatus they found the instantaneous gain of velocity on suddenly removing all the load from the engine which was tested, or the retardation on suddenly changing from the friction load to full load, amounted to from one-sixth to one-quarter of a revolution. The statement that very few engines ran so nearly uniform as 5 per cent. he considered not to apply to American practice, as the variation in speed in engines there used in service, where close regulation was required, was much less than this. There were high-speed engines which the makers guaranteed should run within 1 revolution per minute of constant speed regardless of load, and that the instantaneous change should not be over $\frac{1}{4}$ revolution. In these engines the effect of the inertia of the weights in assisting to operate the governor had been carefully traced by theory and experiment, and the governor was so designed that this effect was introduced in the proper way. That the effect of inertia could be made too great in a governor he pointed out at a meeting of the American Society of Mechanical Engineers, in 1894, where he had presented diagrams obtained from an engine, showing the time required for a shaft-governor to move from one

Prof. Jacobus.

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Prof. Jacobus. position to another when the load was changed;[1] but the advisability of reducing this effect as far as possible, instead of constructing a governor in which it should assist in the action for a sudden change of load, might be questioned. As the Author strove to reduce the inertia as far as possible, tests to determine the instantaneous variation for a sudden change of load would be desirable, in order that the results might be compared to those which have been obtained in governors designed so that the inertia should assist in the action.

Prof. Smith. Prof. R. H. SMITH thought the Author's hydraulic device for automatically keeping bearings in correct adjustment extremely ingenious, and, if it were effective for its purpose without causing trouble in maintenance, it ought to be useful in the main bearings of unbalanced or imperfectly balanced engines. As applied to the connecting-rod, however, the construction seemed too complex to withstand successfully and permanently the unavoidable severe bending stresses due to the transverse acceleration of momentum at any really high speed. He believed that the same results could be obtained for a short period of running by the insertion of an extremely stiff solid spring behind the top brass; but such a spring would require hand-adjustment from time to time to compensate for wear. The fluid in the hydraulic cylinder must act as a very stiff spring; but the essence of the device seemed to be the continuity of the maintenance of exactly correct adjustment, as against wear; or otherwise stated, the continuous maintenance, in spite of wear, of a steady standard minimum pressure on each brass when the load was on the other brass. The Author's design of governor did not seem to be new, and laboured under the two disadvantages:—(1) that the reactive pull of the spur-pinion upon each spring-box was one-sided, *i.e.*, away from the axis of the spring; and (2) that variation of cut-off by change of angular advance alone had long been known to give a bad distribution. The gear was also not reversible except by unkeying and re-keying this pinion on the eccentric bars. The Author stated that "no governor had any value which did not move its slide at every stroke of an engine," and, again, that "a correct throttle governor" should have "such proportions that its natural oscillation was equal to that of the speed of the engine," by which latter phrase he meant the variations of speed arising inside one revolution, or inside the "cycle of operations" of a gas or oil-engine. This idea seemed to be held by a sufficient number of persons to

[1] Transactions of the American Society of Mechanical Engineers, vol. xv. p. 950.

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make it worth while to point out its entire irrationality. The idea is that as the speed of an engine necessarily varies within each period of "impulse"-driving, in so far as the driving moment upon the shaft undergoes periodical variation, therefore the governor ought to act so as to check that variation of speed and prevent its being large. The simplest way of treating this proposition by *reductio ad absurdum*, was to point out that the maximum speed in the periodic variation was reached after the cut-off, while at this phase of the revolution no governor, either throttle or cut-off, could have any effect whatever upon the action of the engine. But if the governor began to move so long before the maximum speed was reached as to operate effectively before cut-off, then the inevitable effect of its operation would be to increase, instead of decrease, the ratio of maximum to average driving moment, and therefore to increase the variation of speed. This would be the result whether it operated by throttling or by hastening the cut-off. So far as governing *per se* was concerned, no possible advantage could result from the governor oscillating rhythmically with the variation of driving moment. Some makers thought that a continuous trembling oscillation was a useful guarantee against risk of "sticking," but this seems to be amply provided for if the governor followed sensitively the variation of average speed, the average being reckoned over the whole period of rhythmic variation of driving moment. The variation of speed inside that period could not be restricted except by fly-wheel action, or else by synchronous variation of working resistance. Prof. Smith.

Prof. R. H. THURSTON thought the Paper embodied many points of interest, originality and suggestiveness. The characteristics of high-speed engine practice, and the difficulties necessarily to be met and overcome by the designer and the constructor of that type of engine, were admirably stated, and the method of construction adopted in the new machine described, when seeking to evade those always formidable objections to that type of engine, was exceptionally ingenious. The trouble so commonly met with in the usual forms of double-acting high-speed engine, of jar and pound, in the line of the piston-connection especially, should be greatly reduced in this as in other engines, by the application of the principle introduced by Mr. Charles T. Porter, of New York, in the first professedly high-speed engine, of which an example was exhibited in London at the International Exhibition of 1862. In this case, the weights of parts along this line of connection were adapted by computation to the proposed speed of rotation, in such manner as to equalize pressures on the pin, as far as possible, Prof. Thurston.

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Prof. Thurston. by balancing the inertia effects of that weight against the varying steam-pressures of a high-expansion steam distribution. It would be interesting to ascertain at what speed of revolution the engine described would attain at what he had been accustomed to call its "natural rate"—that at which the inertia of parts, proportioned simply for strength, as in slow-speed engines, would afford such compensation and such regulation of crank-pin pressures as Porter contemplated.[1] Possibly it might prove practicable to so design the heavy parts as to give efficient application of the Porter principle and thus partly, if not fully, avoid the usually objectionable "knock" in the running parts at these high speeds. This would involve a design of the valve-gear, and a steam distribution, giving a high expansion ratio and resultant wide range of steam-pressure upon the piston, which might be incompatible with the purpose of the designer. The "natural speed" of an engine having 100 square inches area of piston, an initial pressure of 100 lbs. per square inch, a ratio of expansion 4, a weight of running parts of 100 lbs. and a stroke of 1 foot, would be about 500 revolutions per minute.[2] A compromise adjustment must, presumably, always be made in the standard forms of high-speed engine, in which the expansion ratio, the compression and the inertia effects might conspire, in the best practicable manner, to give smooth running and freedom from jar or heating. By such expedients the best builders succeeded in making their engines satisfactorily reliable up to a piston speed, in the usual sizes of this class of engine, of about 600 feet per minute, but there was still opportunity for improvement. The earliest, and the then most serious, difficulty met with in the attempt to produce such an engine as would be satisfactory to the builders of electrical machinery, that of occasional entrance of water into the cylinder, had now been practically done away with by the general use of effective forms of "separator" and of well designed and proportioned boilers. Heating of bearings had been rendered a comparatively rare occurrence, in the better classes of engine, by the general use of "white metal," and, especially, of systems of lubrication which flood the journals and give a continuous circulation of the lubricant without waste. With occasional filtering, good

[1] For a very excellent exposition of this method, see Porter "On the Richards Indicator." London, Elliott Bros., 1874.

[2] $N = \sqrt{\frac{A\,p\,(1-1)}{0{\cdot}000682\,R\,W}}$, "Manual of the Steam Engine," vol. ii. p. 462.

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oils could continue satisfactory for many months, and the flooding of the rubbing surfaces not only reduced liability to heating by its larger oil-supply, but also, and enormously, by reducing the coefficient of friction to a fraction of that usual with the older method of discontinuous, or drop-by-drop, lubrication. Such speeds as were contemplated by the Author were, however, very seldom attempted by builders of double-acting engines. Those building single-acting machines, especially of the Brotherhood and related types, in which practically perfect balance could be secured, had entered with apparent success into this, to the ordinary builder, forbidden territory; and had experimentally, at times, attained speeds exceeding 1,000 revolutions a minute, and, in one case reported to him, 2,700 revolutions, without serious shake or other trouble. He considered the form of bearing, with white metal and bronze alternating, as here adopted, a novel and certainly an admirable plan for increasing efficiency of lubrication. Governing had never in the United States, given much trouble in this class of engines, and the higher the speed of revolution the less the difficulty as a rule. Shaft-governors were universally employed and the regulation was often guaranteed within extraordinary narrow limits. In one case a guarantee had been given by a builder that the engine should never exceed the rated speed by 1 revolution per minute. Many years ago, Professor Sweet, in designing his "straight-line" engine, sought to solve the problem so admirably discussed in the Paper, of reducing friction to a minimum in the governor as well as in the other parts of the machine. Sending his assistants to test one of his first engines, thus designed, the report was brought back that "the engine ran at precisely the same speed, loaded and light"—230 revolutions. On a personal investigation, it was, however, found that the speed without load was 231 revolutions, at more than full load 230 revolutions. It was evident that the reduction of the friction of parts of the governor was one essential in the endeavour to secure close regulation. Mr. Porter, a generation ago, had discovered, also, that with the weighted governor, the strains due to inertia-stresses, from load and balls, must be carefully provided against, and he completely re-designed the loaded governor from that point of view. The ingenious devices of the Author would seem to indicate still further advance in this path. The governor-wheel described in the Paper had a speed of rim of 6,000 feet per minute, which the recent experiments of Mr. Benjamin indicated to be approximately at the limit of safe speed for that detail ordinarily

Prof. Thurston.

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Prof. Thurston. made.[1] Among other minor but excellent details of construction of this engine, it was interesting to observe the precaution taken against the breakage of the cylinder-head by water entering the engine—the long bolts extending from head to head. The device was likely to prove effective. Professor De Volson Wood, in the design of his rock-drills—where this danger was vastly greater than in the steam-engine—adopted this device some 20 years ago, and it had proved sufficiently useful to cause its continued use in that department of engineering. On the other hand, the reduction of "dead spaces," and increase of the expansion ratio at rated loads, would seem likely to prove desirable in larger sizes at least. In the general proportioning of this class of engines it would seem that a comparatively long stroke of piston might be advantageously adopted, since the limiting speed of revolution was, other things equal, independent of the length of stroke. That velocity being attained, increased power and economy might, beyond that limit, be secured by lengthening the stroke. As the loss by "cylinder condensation" was mainly due to the action of the plane surfaces of the interior wall, increasing the stroke reduced the percentage of such loss. In the early years of the century, it was quite customary to adopt proportions of stroke to diameter, double those now employed with even low-speed engines. Possibly some approach to such proportions may yet be seen in this branch of engine construction. He had little question that the constructors of this engine would find it desirable to increase the ratio of expansion, and to compound the machine, to make it generally acceptable. He complimented its designer upon the beauty of the many novel and ingenious devices which he had introduced, and which constitute the engine a new type. Its progress would be watched with great interest by all engineers engaged in steam-engine construction, especially in the department of electrical machinery, where, presumably, it was to find its largest field of application.

Mr. Twinberrow. Mr. J. D. TWINBERROW agreed with the Author's conclusions as to the great usefulness and economy of high speeds and double action, but he thought that the ingenuity which he had devoted to the provision of automatic adjustment had gone somewhat beyond the restraint due to considerations of cost. The sole justification for quick rotation lay in the provision of power at less total cost than that possible by other means, and it appeared likely that the expenditure of labour in carrying out the Author's design

[1] Transactions of the American Society of Mechanical Engineers, 1898.

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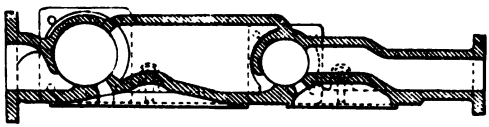
might be greater than the savings resulting from the reduction of size. The working of the hydraulic rams seemed to be closely analogous to the action of forced lubrication. In the first case, when the journal tended to leave the brass the fluid flowed in at the back of the ram, under atmospheric pressure, and on the return of the journal, prevented a knock by exuding slowly past the valve as the pressure increased. In the case of forced circulation, a void Mr. Twinberrow.

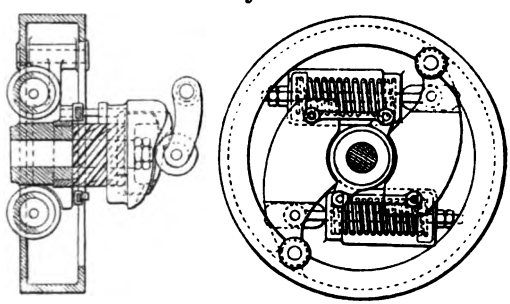
Fig. 8.



Scale, 1 inch = 1 foot.

was instantly filled by the lubricant covering the surfaces with a film, the tenuity of which was reduced by lateral flow to that capable of sustaining the working pressure. If the pressure of supply was sufficient to fill all voids before the return of the journal, and if the amount of slackness did not exceed ordinary limits, the latter method appeared to possess all the good points of the former at greatly reduced cost, with the further advantage of effecting perfect lubrication which reduced wear to a vanishing

Figs. 9.



Scale, 1 inch = 1 foot.

quantity. The large cylinder clearance-surfaces in the long ports and deep pockets around the covers, as shown in Figs. 1, Plate 1, would seem to be particularly undesirable in a non-compound engine. In order to reduce such surfaces to a minimum, it appeared to be advantageous to place the valves in the cylinder heads, as shown in *Fig. 8*, which showed the top cover of a compound engine, recently designed in collaboration with Mr. G. H. Sheffield,

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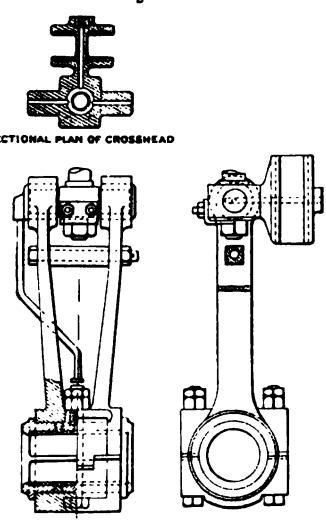
Mr. Twinberrow.

A.M. Inst. C.E. The valves were driven by means of a crown cam fixed on the end of the crank-shaft within the casing, working in contact with rollers which were coned to ensure constant velocity of the surfaces in contact, *Figs. 9*. The profile of the cam was developed to parabolic curves of a range suitable to the determination of the lead, exhaust and compression. The fixed cam was surrounded by another which was helically rotated thereon by the movement of the governor weights, and the rollers were sufficiently long to bear across the working faces of both cams; the moving cam was shaped to increase the travel of the rollers after the admission and to keep the valves open to steam for longer or shorter periods according to the position of the weights. *Figs. 10* show the method by which the lubricant is conducted to the connecting-rod bearings, obviating the drilling of the shaft, or the employment of swivel-jointed tubes. They also indicated the small number and simple nature of the parts connecting the piston to the crank. Owing to the proximity of the centre lines in this design the vibrating couple was less than half the value of that in cases where the cylinders were separated to admit a valve between them. The Author's contention that an improvement of 5 per cent. in the variation allowed by the governor would cause a similar advance in gross receipts did not appear obvious. The performance of the groups or units which were working under full load would scarcely be affected by the precision of the governor action, and supposing the average output of any set to be improved by 5 per cent., the utmost economy which could be credited to the better governing would be a corresponding saving in interest and depreciation, owing to the better utilization of plant. On the other hand, the importance of close regulation in generators of alternate currents could not be over-estimated, and it would be of interest to learn whether the excellence of the Author's governor was maintained when subjected to the necessarily greater reaction of larger valves with longer travel.

Figs. 10.



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Mr. J. H. DALES, in reply to the Correspondence, said there was no wear or deterioration of the parts except such as the chemical effect of the liquid on the rams might produce; and this, with mineral oil as ordinarily used on engines and non-corrosive packings, was negligible. The automatic adjustment accomplished at all rates of reciprocation, the prevention of heating which was effected by forced lubrication only up to a certain rate of reciprocation; moreover, this was effected at speeds which were quite impracticable with the clearance necessary to work forced lubrication. As the results of automatic adjustment were so marked at the extreme rates they must be equally beneficial at lower speeds. Further, no uniformity of fit was necessary for the successful working of the automatic adjustment; whilst the allowance of sufficient clearance in fixed bearings to avoid seizure was quite impracticable even at comparatively low speeds, seeing that between 60° and 400° (white metal melts at about 440°) a 6-inch shaft and brasses of $1\frac{1}{2}$ inch, or $7\frac{1}{2}$ inches total of metal of, say, equal expansibility to steel, would require a clearance of quite $\frac{1}{60}$ inch when cold. A fast engine with such a clearance would immediately hammer its bearings hot. Of this he had had actual and repeated proof. The excess of cost over that of a similar engine with fixed bearings was, in the case of the 300-HP. compound engine, £23 12*s.* 6*d.*, and an engine of the size named could be sold for £300 less than a so-called ordinary high-speed engine. With good clean metal of different hardnesses for the valve and bore, and a good well-bedded parallel fit to start with, as well as the necessary clearance fit, so that the surfaces did not get spoilt by jamming in the beginning, solid cast-iron piston-valves lasted remarkably well, and the proportionate weight of steam which escaped over and above what would occur with slide-valves was a very small item. The governor of the 300-HP. engine had a centrifugal force of 7,000 lbs., but he should never set it to work a slide-valve, especially with a pulling spindle, for the sake of what a slide-valve would save over a good piston-valve. The better quality of governing obtained with a piston-valve would alone pay the leakages many times over. He quoted the 9 per cent. variation of a Corliss engine, to show the extent to which good governing was neglected by even many makers of repute; and not to make out that so close governing as 1 per cent. could not be obtained by any means but those dealt with in the Paper. It was a refinement which had been very rarely attained under such conditions by either shaft or other governors in ordinary use, and the maintenance of the quality when years of wear had taken

Mr. Dales.

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Mr. Dales. place had, he thought, been even more rarely accomplished. It was this permanence of quality which it was sought to produce in the design dealt with—something indeed which would improve rather than deteriorate by wear. This was precisely the outcome of the simple arrangement shown. The very light friction of the spring in its guide was accounted for by the fact that a spiral spring, even very heavily loaded, could be kept in line when under compression by a very slight lateral support. A few pounds lateral support would maintain the line of a long spring loaded to 2,000 lbs., and the friction of this support as a percentage of the total centrifugal force was negligible. For testing variations of speed he had generally depended upon a voltmeter where available. An appliance which would govern to 1 per cent. was actually a more delicate instrument than any of the portable instruments constructed on centrifugal principles which were obtainable.

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17 January, 1899.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

(*Paper No. 3123.*)

"The Effects of Wear upon Steel Rails."

By WILLIAM GEORGE KIRKALDY, Assoc. M. Inst. C.E.

To the subject of this Paper considerable attention was devoted by the late Mr. David Kirkaldy, M. Inst. C.E., who advocated and had hoped to see adopted standard sections for rails of definite weights as well as standard specifications as to the quality of the steel. He also particularly wished to ascertain the relative wearing capacities of different qualities or grades of steel; and had frequently suggested that representative rails from various "blows" (selected according to their grade as determined by preliminary mechanical tests) should be laid down and a record obtained of their actual behaviour under traffic, with the intention of making further mechanical tests upon them at various periods after considerable service. But he was not successful, at least to his knowledge, in persuading railway engineers to enter upon this systematic treatment and investigation at the time when steel rails were being brought into use. Had such investigation been set on foot in those early days the subject could have been treated more conclusively long ago.

An opportunity was given for carrying out a series of experiments bearing upon this subject in November 1895, when the Author's firm was instructed to test and report upon portions of a steel rail which had broken on the Great Northern Railway. Similar experiments were subsequently authorized by other railway companies, and, through the courtesy of the engineers, the Author is enabled to place the detailed results of many of the experiments before the Institution.

In the first instance, two short pieces of rail were experimented upon, the rail having been broken into very short lengths. It was thus impracticable to make any bending tests at that period, and

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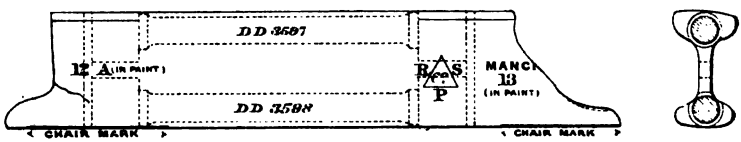
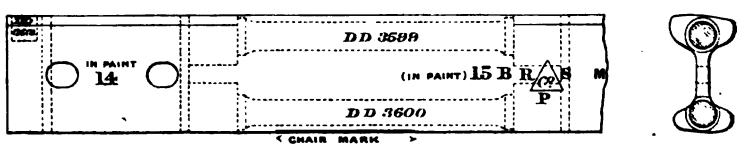
information had to be obtained wholly from the tensile tests. A careful sketch was first made of each of the samples, showing the positions of the chair-marks and the original fractures. According to standard practice, two tensile specimens were then prepared from each piece, one from the top or head, and the other from the bottom of the rail.

The results obtained from tests of the bottom member of each piece of rail showed the steel to be normal and uniform; in fact, the quality of the steel was fairly within the average obtained in new rails of ordinary make. The question as to whether the rail might have been an exceptional one was thus early set at rest. In the case of good new rails there is practically so slight a difference between the quality of the steel in the top

Figs. 1.



Figs. 2.



Scale, 1¼ inch = 1 foot.

ORIGINAL FRACTURES OF THE RAILS, SHOWING THE POSITIONS OF THE TEST-PIECES.

and in the bottom that no distinction need be made. In the case of double-headed rails there is no difference, owing to the section being symmetrical, whereas in the case of bull-headed rails the slight difference found in testing is no doubt due to a different amount of work being done upon the steel in rolling, on account of the variation in cross-section, and also to the slight difference in the rate of cooling between the thick top and small bottom; but this difference may be ignored for the purposes of comparison throughout the experiments here recorded.

The behaviour of the specimens prepared from the head of each piece of rail showed that the steel is in quite a different condition from that in the bottom of the rail. The tensile strength of the bottom, *Figs. 1*, was found to be 94,110 lbs. per square inch, with a

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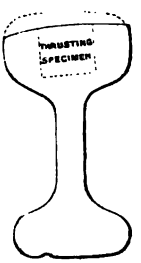
contraction of area at fracture of 30·6 per cent., whereas in the top the tensile strength falls to 88,840 lbs. per square inch, and the contraction of area to only 5 per cent. The appearance of fracture, moreover, was completely changed. But the tests of the piece shown in *Figs. 2* disclosed even a more marked deterioration or change in the head, the tensile strength of the bottom member being 94,145 lbs., which, in the case of the head, drops to 58,100 lbs. The contraction of area from 37·1 per cent. fell to only 1·5 per cent., the toughness of the steel having practically vanished. This specimen proved particularly valuable, as it afforded evidence of the immediate cause of the breakage. Special note was made of the presence of a slight flaw, which accounts for the great diminution in strength, and which had distinctly been induced by wear; it was not a defect in the manufacture or a flaw originally in the steel. It only just encroached within the body of the test-specimen, and justified the forethought in preparing the specimens so that the bodies should lie as near the original surface as possible. Had this specimen been prepared lower or of smaller diameter the flaw would have been removed in the turning, and trace of its existence lost. Judging from the behaviour of the specimens from the heads of these two short pieces of rail, the deterioration arose primarily from what may be termed "hammer-hardening" of the running surface, caused by the passing of the wheels of trains; and following upon this hardening the development of minute cracks—transversely to the length of the rail—which had gradually extended or penetrated downwards into the rail-head from the hardened top surface.

Fig. 3.



Scale, 3 inches = 1 foot.

The deterioration having been found from the tensile tests to lie entirely in the top of the rail, the impression formed from an examination of the original fractures was confirmed. The form of fracture, left-hand end, *Figs. 1*, is typical of fractures produced under bending, and the piece shown partly detached in the *Fig.* is invariably found on the compression side of the specimen. It was thus conclusively shown that the original fracture had taken place through the top of the rail failing, while that portion was placed in tension through the reverse flexure of the rail under the travelling load; and, moreover, that fracture lies immediately over the place where the rail was supported by a chair and sleeper, as shown by chair mark or gall on the underside.

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For the purpose of making a test under thrusting stress a cylinder 1 inch high and of a diameter giving an area of 1 square inch was prepared from the head, *Fig. 3*. The outer top line represents the original section traced from the standard, and is reproduced to illustrate the amount worn off the rail. The thrusting specimen was prepared as close as possible to the surface of the rail-head; in fact, the rail was held in the lathe so as to merely require a light cut or scrape for truing the top end of the specimen. Its behaviour under pressure was very interesting, as the metal spread only slightly at the top face, but more freely on the underside of the head towards the web, demonstrating clearly the hardening produced by wheel traffic. In the case of new steel rails the cylindrical specimens always assume a more or less barrelled shape under thrusting stress. The thrusting test affords a good comparison of the relative hardness of the steel in various rails, by comparing the amount of depression or shortening under definite pressures, for instance, at 100,000 lbs. and 150,000 lbs. per square inch. The density of the thrusting specimens has been determined throughout the experiments upon worn rails, but no conclusions have been formulated. It seems probable that this will not afford sufficiently emphatic data, but the Author considered it important to ascertain this information from the commencement, in the event of its proving serviceable later in the course of the investigation.

After these initial tests and reports upon the first pieces of rail were completed, the results obtained were carefully considered by the engineers, and the Author had an opportunity of examining other fractures of the broken rail. Clear evidence was then obtained that in almost every fracture an induced flaw existed. This can best be illustrated by *Figs. 4*, *5*, and *6*, which have been reproduced from two additional pieces of rail marked J and K which were then selected for further tests; these pieces were from the rail adjoining the one already referred to. The short piece J was used for tensile tests, and the results showed a serious diminution of strength in the top or head of the rail (as compared to the bottom) accentuated, and accounted for, by the presence of an induced flaw which had penetrated from the top surface and partly across the body of test-specimen. The tensile strength of the bottom was 100,060 lbs. per square inch, whereas the top only reached 32,070 lbs. It is interesting to compare this flaw, *Figs. 4*, with the large flaw shown in *Fig. 6*, which represents the end fracture of same rail. These flaws were similar in extent of penetration, although only a portion is preserved in the case of

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the test-specimen, owing to the outer part of the head being necessarily turned down to obtain a suitable form for testing. The short distance between these two flaws should be noted; they were only about 9 inches apart. The piece marked K,

Figs. 4.

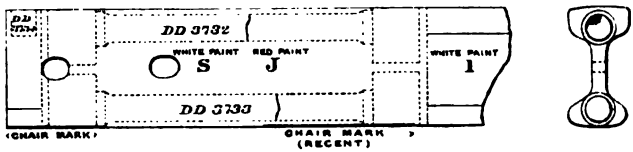
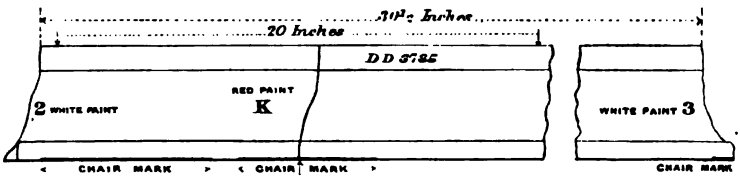


Fig. 5.

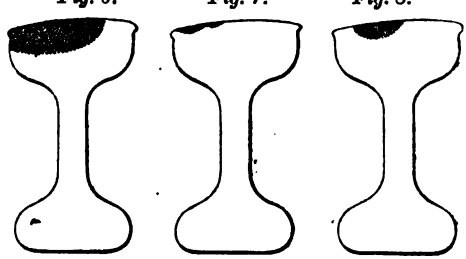


Scale, 1½ inch = 1 foot.

ORIGINAL FRACTURES OF THE RAILS, SHOWING THE POSITIONS OF THE TEST-PIECES.

Fig. 5, was used merely to obtain a clean fresh fracture, as the Author expressed the view that it was possible and probable that the rail was subject to these flaws in other positions besides those in which fracture had actually taken place. It will be seen from the full section of original fracture, *Fig. 8* (which represents the one at right-hand end of *Fig. 5*), that there existed a flaw of considerable extent as shown by dotted region. In order to produce a new fracture by bending, the point selected for the centre bearing was at a recent chair-mark or gall. By bending the rail upward from this point—that is, with the top in tension—a fracture was obtained, and, as shown in *Fig. 7*, two induced flaws were found, practically forming one, as they

Fig. 6. *Fig. 7.* *Fig. 8.*



Scale, 3 inches = 1 foot.

SECTIONS SHOWING FLAWS IN RAILS, *Figs. 4* AND *5*.

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appeared to have extended and merged together. The load at which the rail broke was very low compared with that which would be inferred from the original quality of the steel, had the top not been so seriously deteriorated or affected by the presence of these flaws. The induced flaw in this fresh fracture was but very shallow; it had not penetrated to nearly the same extent as those found in the original fractures, *Figs. 6* and *8*. It will readily be appreciated that if this shallow, almost insignificant, flaw caused the rail to break at only about one-half of its normal strength, the strength of the rail while in the permanent way must have been excessively reduced at the points where the flaws had extended to such an abnormal amount. In other words, the failure alluded to is fully accounted for.

The reason that a recent chair-mark was selected as the position for the central bearing in the bending test, was that the Author inclined to the belief at that period that flaws would be likely to occur in the vicinity of and over the chairs, as there appeared evidence of the rail being hardened rather more over the chairs than between them. This may be accounted for or explained by regarding the chair somewhat as an anvil; the unsupported portions of the rail are partially relieved by deflecting, whereas, those resting on a chair being much more rigid are apt to be more punished by the traffic. The term "recent" chair-mark is used on account of these two worn rails having been previously laid in a different position and with a supported joint, thus there were two sets of chair galls, but for the purpose of the investigation positions of the chairs as last placed were of chief interest.

A close examination of the worn surface of this rail, when cleaned and polished, exhibited the presence of a multitude of cross flaws—in fact, the head was practically disintegrated. The surface was also intensely hard; a tool could scarcely be made to touch it.

As the result of these early experiments the Author recommended that lengths of rail should be taken out of the line adjacent to the rails referred to and submitted to further experiments. This suggestion was promptly acted upon, and six samples of worn rail of the same quality, *Figs. 9*, were selected. As more material would thus be available the Author decided that in all further experiments upon worn rails the most reliable method of determining their condition would be to make bending tests in duplicate, first by bending the rail with the head in compression, and, secondly, with the head in

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tension. These bending-tests were to be followed by tensile tests for the purpose of ascertaining more especially the original quality of the steel as shown by specimens prepared from the bottom of each rail. The tensile tests are important as yielding data in a standard form, but the Author foresaw that the "inverted" bending test would be of immense service in detecting even the slightest deterioration, although perhaps merely superficial, whereas the tensile test cannot always include the portion of the steel that may be deteriorated, especially if the deterioration has penetrated only slightly beneath the surface. It is necessary for tensile tests to prepare the body of the specimen suitably by turning, thus entailing the removal of some of the metal, and, notwithstanding that the Author has caused specimens out of rail-heads to be prepared as near to the surface as compatible with reliable tests, it has been found that the deterioration is not always detected by that class of test.

The merit of duplicate bending tests made in reverse directions lies in the comparison thereby obtained. In the case of a new rail the behaviour under bending is practically alike whether the rail be bent upwards or downwards. With the head downwards or in tension the rail is naturally stiffer, and the maximum load carried should be greater, but in actual testing it is frequently found that buckling or deformation ensues, owing to the bottom or small table of the rail not being stiff enough to resist the compressive force set up. Thus the maximum load is as a rule about the same as in the normal direction. In the case of a worn rail, so long as it is tested in the "normal" direction, that is, with the bottom member in tension the rail behaves like a new one. Whereas when an adjacent portion of the same rail is tested in "inverted" direction, so that the worn head is placed under tension, if it be deteriorated, even in a slight degree, it produces a very sensible difference upon the result of the test.

The bending test adopted is not a crude falling-weight test, which has always been avoided by the Author, following the views and example of his father. Neither is it the incomplete bending test under pressure with few observations as now employed at some makers' works, which certainly is a great advance over the drop-test. It is a test by pressure in which the central load is gradually applied, and a complete series of observations of the rate of deflection is obtained as the load is increased, the deflections being recorded at increments of 2,000 lbs. By this elaboration

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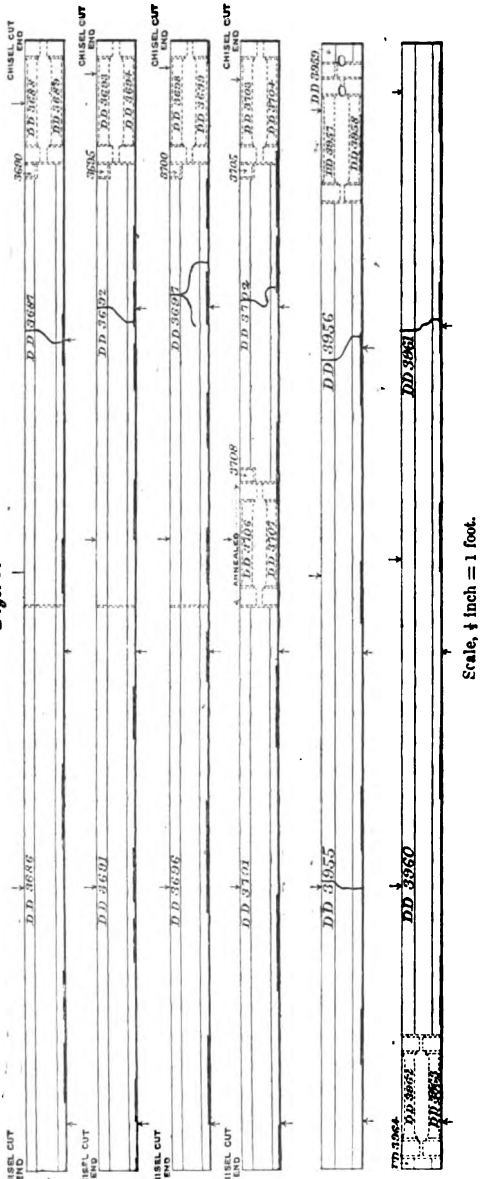
any difference in the behaviour of the rail is made manifest, and judgment can be formed without having to rely upon the ultimate or maximum results alone. The deflections at intervals are particularly useful for comparison in cases where rails buckle, as the ultimate load is affected according to whether buckling ensues at an earlier or later period of the test. The span of 5 feet was adopted many years ago as a standard for comparison. A shorter span of 3 feet is not considered desirable as it is apt to convey a false impression; no rail, the Author believes, has ever failed upon such a short span. The trouble usually arises through the yielding or sinking of a sleeper, and in that case the span is at once greatly increased. Therefore the 5-foot span is still considered the best practical one that could have been selected.

Figs. 9.



Scale, ½ inch = 1 foot.

SIX WORN RAILS SELECTED FROM POSITIONS IMPOSING SIMILAR CONDITIONS.

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The six rails of the same manufacture, worn under similar conditions and removed from the same part of the line as the fractured rails, were tested for their resistance to deflection in both directions, as the pieces were each 12 feet long, *Figs. 9*. Their behaviour demonstrated how well the "inverted" test reveals any deterioration in the rail. To mention only one instance, in the case of the first rail, when it was bent in the "normal" direction, the maximum load or stress was 59,640 lbs. and the rail was removed unbroken at a deflection of 6·0 inches, when the test was discontinued. In the inverted test the same rail reached a load of only 33,980 lbs. when it snapped at the low deflection of only 0·28 inch. The very low results obtained in this inverted test are accounted for by the presence of two induced flaws, proving the unfitness of this rail for further service. The other five rails also showed deterioration, but not to the same degree, Table I, Appendix II.

CHISEL CUT
WHITE PAINT
STEEL E.V.C°LP 71 G.N.R.
STEEL PEECH & TOZER SHEFFIELD G.N.R. 3.1894
S. FOX & C° STOCKSBRIDGE 1890
S. FOX & C° STOCKSBRIDGE
WILSON & CAMMELL DRONFIELD STEEL 1875 G.N.R
5'. 0"

Figs. 10. FOUR WORN RAILS SELECTED FROM POSITIONS IMPOSING VARIOUS CONDITIONS; WITH ONE NEW RAIL.

Scale, ½ inch = 1 foot.

Four rails, *Figs. 10*, selected from various parts of the line imposing various conditions, together with one new rail, were subjected to the same tests. The last rail in the group had been subject to

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brake action, and is perhaps the most interesting. The wide divergence in behaviour under the "inverted" from the "normal" direction of test is very instructive. While the rail bent to 7 inches in the normal direction without breaking the deflection was only 0·36 inch when it snapped under the inverted test, the maximum loads being 61,440 lbs. and 35,400 lbs. respectively. The fourth rail is also interesting; it is described as having had 10 years' service, and deterioration had distinctly set in, the deflections being respectively 8 inches unbroken and 1·44 inch when fracture ensued; the loads being 73,130 lbs. and 52,260 lbs. respectively. The third rail, described as "85 lbs. in road 5 years with heavy wear," is still in excellent condition, there being no appreciable deterioration, as it did not snap under the inverted test. The first rail in the list is likewise in very fair condition. It may be considered as of exceptional interest from the fact of its very long life and remarkably good wearing properties; indeed it might be well described as an ideal rail. It was for information on this kind of rail that the Author was seeking when he suggested that a length of rail which had been found to wear exceptionally well under the longest life which could be verified, should be obtained from a situation where the conditions were favourable. This rail had been in the main line for about 23 years at a point between 62 miles and 63 miles down the line where the road was level, and remote from any signal cabin or station, so that in all probability no train had ever been stopped upon it. To all appearance the rail was still in splendid condition, and the loss of weight per yard was remarkably small, originally 80 lbs., nominal, reduced to 77·62 lbs. The rail behaved very well under bending, and although it broke when tested in the inverted direction, yet as the substantial deflection of 4·19 inches was reached before failure ensued, the condition of the rail must still be considered good, Tables II and III, Appendix II.

The Author had realized from the commencement of the experiments that it would be easy to fall into the possible error of taking an alarmist view of the question, but feeling the very grave responsibility resting upon him, he anxiously avoided the formation of a despondent view as to the condition of rails in general. He strove to allay any feeling of alarm with its concurrent tendency to relaying upon an extensive scale, necessarily involving great outlay. The outcome of the experiment last referred to was therefore very gratifying and encouraging, and the Author considers it to be of immense import and value to railway engineers.

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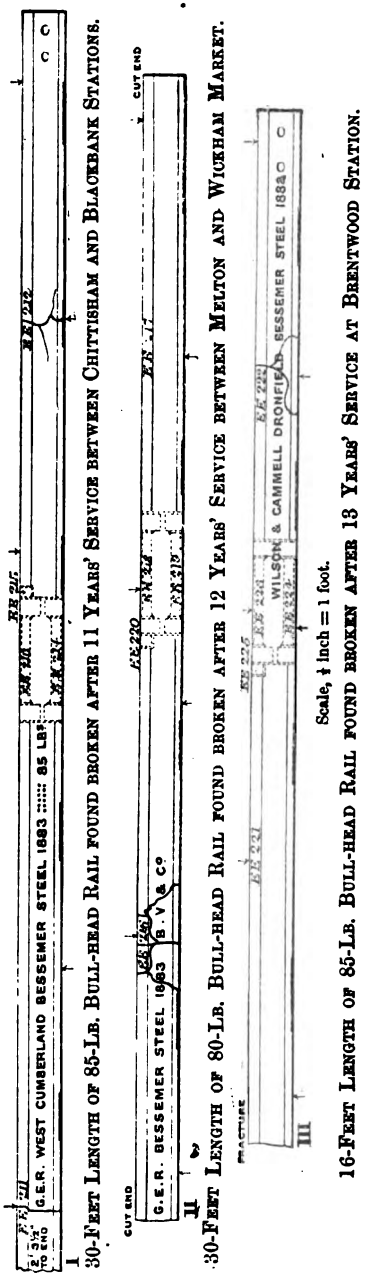
While anxious to avoid risk of accidents to the public or damage to rolling stock and permanent way through the breakage of rails, the Author felt that it would be wiser to investigate and ascertain as nearly as possible the actual condition of affairs before any serious action was taken. He thought that prompt attention should be given to all positions where rails were subject to unfavourable conditions, thinking it only judicious to make some, perhaps unnecessary, renewals at such points, rather than incur any risk.

Examples were obtained from the Great Eastern Railway; the Author is enabled to embody the results of tests upon them through the courtesy of the engineer, Mr. John Wilson, M. Inst. C.E. *Figs. 11* show the positions of bending and pulling test-pieces in three rails which were found broken; the appearance of the fractures and sections of same is shown in *Figs. 12*. Rails No. 1 and No. 3 show the typical induced flaws, and their behaviour under bending also was characteristic, showing the progress of deterioration. The defective portion of rail No. 2 is shown in *Figs. 13*; this rail is interesting from the fact that, although the end had fractured in the line through the fish-bolt holes, such failure was entirely due to local defect

Figs. 11.



30-Feet Length of 85-Lb. Bull-head Rail found broken after 11 Years' Service between Chittisham and Blackbank Stations.

30-Feet Length of 80-Lb. Bull-head Rail found broken after 12 Years' Service between Melton and Wickham Market.

Scale, ½ inch = 1 foot.

16-Feet Length of 85-Lb. Bull-head Rail found broken after 13 Years' Service at Brentwood Station.

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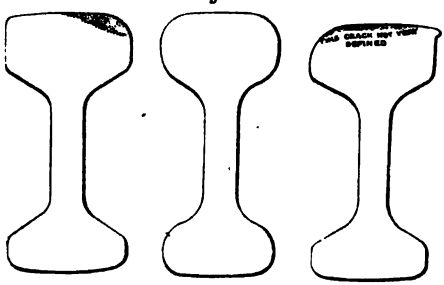
originally in the end of the rail. There was distinct proof of this unsoundness being part of the crop or top end of the ingot and that insufficient metal had been removed in finishing the rail. The bending test showed the rail to be abnormally hard yet tough withal and free from deterioration, the rail deflecting 5 inches in the normal direction before breaking and 6 inches in the inverted direction, when buckling ensued: the maximum load sustained being abnormally high in each case, viz., 119,820 lbs. and 121,720 lbs. The rail, in fact, remained in excellent condition after 12 years' service, and the Author believes would have given a satisfactory account of itself for many more years had it not been removed, owing to the short defective end.

Figs. 12.

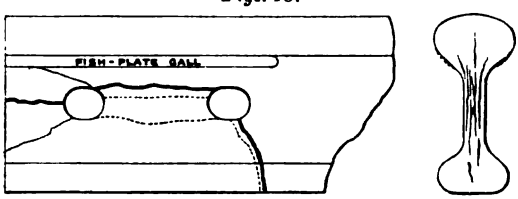


Scale, 3 inches = 1 foot.

CROSS-SECTIONS SHOWING FLAWS IN THE RAILS, *Figs. 11.*

The tensile tests of specimens from these rails showed that No. 1 and No. 3 gave respectively 51·5 tons and 47·6 tons per square inch. The tensile strength of rail No. 2 is unusually high, viz., 60 tons per square inch. This rail would doubtless not have been accepted for use had its quality been noticed under the original inspection; it had probably been overlooked, yet it yields very interesting information, tending to show that a much harder steel than usually employed can be used without risk of failure, and the Author inclines to think even with distinct advantage.

Figs. 13.



Scale, 2 inches = 1 foot.

END OF RAIL II, *Figs. 11.*

Through the enterprise of Mr. Wilson opportunity was given for investigating the benefit to be derived from annealing rails, with a view to possibly adopting such treatment if found feasible. For the purpose of the investigation six rails were selected from a position where they were subject to severe wear. The entire rails

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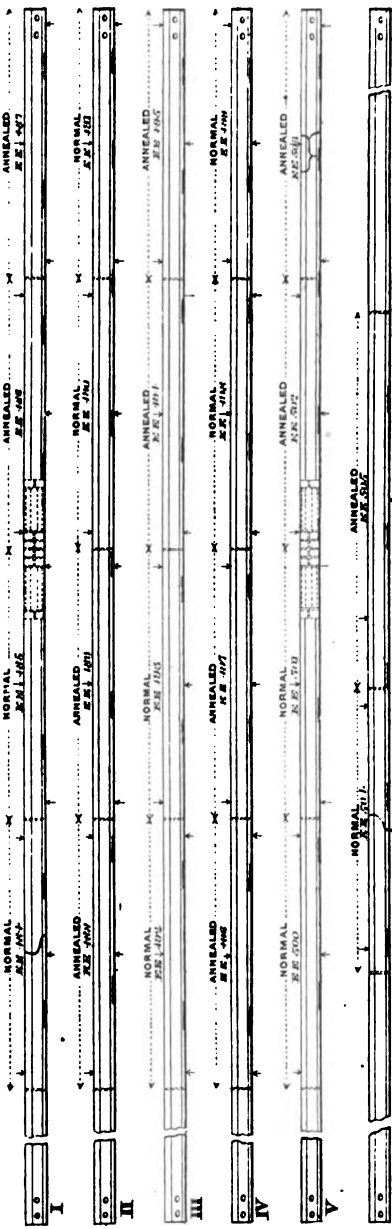
were sent to the Testing Works and were there cut as shown in *Figs. 14*, and certain portions of each were afterwards carefully annealed; their cross sections are illustrated in *Figs. 15*. The general result showed that annealing restored those particular rails to practically their original condition, but the rails were found to be in remarkably good condition as to absence of induced flaws or defects before they were annealed. Had a flaw been started in any of the rails, to however slight an extent it had developed, no amount of annealing would have rectified it, and the rail would yet prove treacherous although annealed. In order to be certain of



Figs. 14.

WORN 80-LB. RAILS, 30 FEET LONG, TAKEN FROM ROAD BETWEEN CAMBRIDGE HEATH AND LONDON FIELDS, ORIGINALLY LAID IN 1881.

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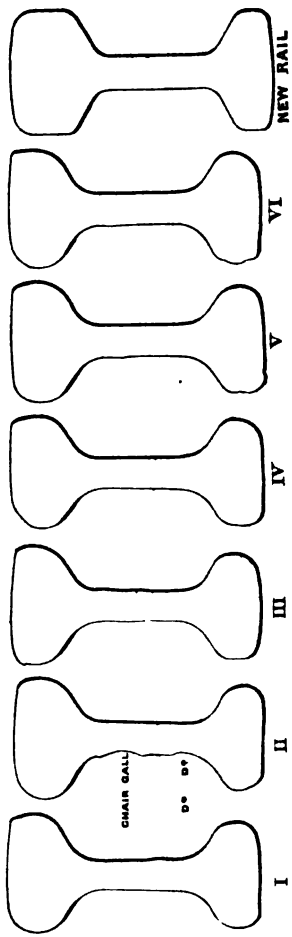
avoiding the presence of flaws it would be necessary not to delay the annealing process too long, and consequently rails would need to be dealt with possibly after only a very moderate life, which would cause very heavy expense, rendering annealing impracticable.

The steel in these six rails was of good average quality, with the exception perhaps of the hardest rail No. 5, which together with No. 1, the softest rail, was selected for pulling tests. In this and in all cases where a number of rails are tested under bending stress it is the Author's custom to test for tensile strength only a few representative specimens, selected from the whole number according to their grade as shown by their behaviour under bending. The fact of these six rails being in such good condition after about 15 years' hard wear is very encouraging for railway engineers.



Figs. 15. Scale, 3 inches = 1 foot. CROSS-SECTIONS OF THE WORN RAILS SHOWN IN *Figs. 14.*

The benefits to be derived from annealing were also the subject of investigation under the action of the Great Northern Railway; the samples were distinctly softened and the surface hardening of the head of the rail was removed, so that the rail behaved quite normally. In that case again, the rails selected did not contain any induced flaws, so that the annealing process showed to full advantage.

The behaviour of six rails selected for testing after 20 years' service, from portions of the same line which were under consideration for renewal, proved them to be still in excellent condition. The rails were taken from situations representing various conditions of work and degrees of traffic.

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The behaviour of rails under various conditions obtaining upon the Metropolitan Railway, where the trains are very frequent and constant, was ascertained by tests upon three rails selected by Mr. Gates, M. Inst. C.E., as showing good examples of the type of flaws set up under wear. It may be noted that in one length of rail flaws were set up and had developed extensively at four different parts of the rail, *Figs. 16* and *17*. This rail was not subject to brake action, while the other, *Figs. 18* and *19*, was subject to severe brake action, but as both have suffered or deteriorated very similarly, the Author would merely draw attention to the very soft nature of the steel in both rails, namely, an average of 33·5 tons per square inch. The fact that they have deteriorated so greatly strengthens the opinion which the Author has long held that a harder grade of steel might safely be employed for rails than has been the practice hitherto. Certainly the softness of these rails has not protected them from very severe and comparatively rapid deterioration. In the first rail there are holes where the fractures marked A and B occur, and also on each side of fracture C. These holes were drilled by the platelayers, owing to a small flaw being detected between the two points A and B, and another at C; a pair of fish-plates was then bolted on at both places to secure the rail, in case of the flaws extending and causing fracture. The rail could not be removed at that period owing to traffic and other difficulties. Evidently when the rail was slightly weakened at the points A

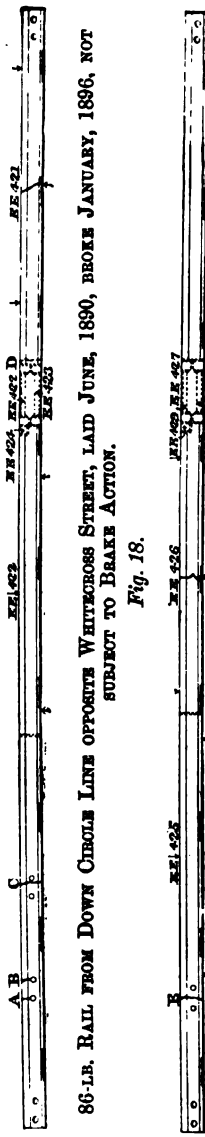

Fig. 16.

86-LB. RAIL FROM DOWN CIRCLE LINE OPPOSITE WHITECROSS STREET, LAID JUNE, 1890, BROKE JANUARY, 1896, NOT SUBJECT TO BRAKE ACTION.

Fig. 18.

Scale, ¼ inch = 1 foot.

86-LB. RAIL FROM WIDENED LINE AT ALDERSGATE STREET STATION, LAID JUNE, 1890, BROKE FEBRUARY, 1896, SUBJECT TO SEVERE BRAKE ACTION.

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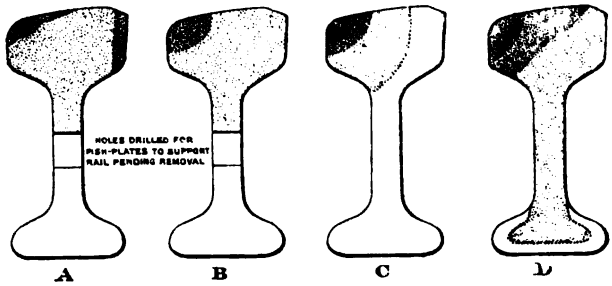
and B by the drilling of these fish-bolt holes, two flaws which

Figs. 17.

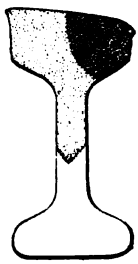


Scale, 3 inches = 1 foot.

CROSS-SECTIONS THROUGH FLAWS OF RAIL SHOWN IN *Fig. 16.*

had already extended considerably into the rail-head (shown by the darker dotted regions in A and B, *Figs. 17*), although they had not been detected, commenced to extend so rapidly that within the course of a few days the rail-head had cracked down to these holes, but the two cracks stopped there, and the rail was removed without any damage resulting, although none too soon, as the other flaw, C, further along the rail, had also developed very rapidly and resulted in fracture. When the rail was being removed it broke in yet another place, marked D, section shown in *Figs. 17*. The induced flaws in sections, *Figs. 19* and *21*, are also well defined and worthy of examination.

Fig. 19.



Scale, 3 inches = 1 foot.

CROSS-SECTION OF RAIL SHOWN IN *Fig. 18.*

The section, *Fig. 22*, illustrates a flaw which had developed in a rail-head, but which probably was the outcome of a defect or scab originally in the rail; in this respect being distinct from all the other flaws referred to, which were entirely induced under wear. The remainder of the rail, *Fig. 23*, remained in excellent condition as proved by inverted tests made at four different positions.

Fig. 20.

Scale, ½ inch = 1 foot.

PORTION OF RAIL FROM UP WIDENED LINE NEAR BARBICAN BOX, NOT SUBJECT TO BRAKE ACTION.

One feature, which has been proved by all the tests carried out by the Author, is, that the deterioration of steel rails is confined entirely to the top or running side; the

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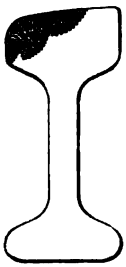
steel on the underside or bottom member does not alter appreciably from the state in which it was when made. This is an interesting and useful point to note, that the constant deflection of rails does not appreciably affect them or produce "fatigue." The deterioration produced on the top is from mechanical action. It could hardly be described as "fatigue" of the metal, as it is not caused by overstraining, but rather by mere mechanical hardening due to the rolling and beating action of the wheels. The deterioration may be classed under two heads: (*a*) increase in hardness, with a corresponding loss of toughness, which is not detrimental, until it develops into the further and really serious stage of (*b*) disintegration, or the setting up of induced flaws or cracks, transversely to the length of the rail; which through gradual development lead, sooner or later, to failure, unless previously detected and the rail removed.

Fig. 21.



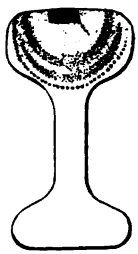
Scale, 3 inches = 1 foot.

CROSS-SECTION OF RAIL SHOWN IN *Fig. 20.*

The following questions suggest themselves in dealing with this subject:—

1. Do all rails suffer alike as to the nature of the deterioration?
2. Does not the quality of steel affect the resistance of rails to deterioration?
3. Does not the commencement and progress of deterioration of any rail depend upon, and vary greatly with, the nature of the traffic, but still more upon the special conditions of its situation?

Fig. 22.



Scale, 3 inches = 1 foot.

Fig. 23.

Scale, 1 inch = 6 feet.

BROKEN RAIL ON UP MAIN GREAT NORTHERN LINE NEAR THREE COUNTIES, NOT SUBJECT TO BRAKE ACTION.

The conditions due to "situation" may for the purpose of investigation be classified as follows:—

(*a*) Effects of wear upon rails situated under favourable conditions; for instance, when on the level, straight, and free or nearly free from stoppages of trains.

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(*b*) Effects of wear upon rails situated under unfavourable conditions; for instance, where subjected to brake action more or less severe.

(*c*) Effects of wear upon rails situated at the starting-position of trains, where the skidding or climbing action of the driving-wheels of locomotives come into play.

(*d*) A subsidiary class may have to be included in the field for investigation, namely, whether it may ultimately be found necessary to make any distinction between the effects upon rails situated on inclines, *i.e.*, between the rising and falling gradient. Probably the effects due to brake-action will fully cover the latter and the effects due to starting-action may suffice to embrace the former subdivision.

These questions are recapitulated to emphasize what appear to the Author to be the leading features of the investigation, but it will be necessary to collect much more data from actual examples before any final conclusions can safely be formulated.

Some of the questions may, however, be tentatively answered as follows:—

1 & 2. It appears that all ordinary grades of steel suffer in the end from the first degree of deterioration or increase of hardness, but some resist the further progress of the deterioration very much better than others. Soft steel does not appear to give greater safety, but possibly the reverse. The harder grades (combined with toughness) appear to have resisted the deteriorating influences much better. So long as a rail be not brittle, it is allowable and desirable, for the sake of gaining greater resistance against the induction of flaws, to use a harder steel and dispense with a proportion of the ductility usually required at present. This is a most important matter that should be decided as to the limit of hardness consistent with safety. The drop or falling-weight test has possibly tended towards the manufacture of rails from unduly soft steel.

3. (*a*) Where the conditions are favourable steel rails of ordinary grade appear to stand remarkably well up to a very long life. Rails have been found to be, practically speaking, free from deterioration after even 23 years' main-line service; (*b*) the trouble arises more with rails situated under unfavourable conditions, but the subject has not as yet been sufficiently investigated for definite conclusions; (*c*) this is a very important "situation" to deal with (in further investigation); the Author has as yet been unable to obtain any rails definitely selected from the starting position of locomotives, with a view to ascertaining the effects of

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wear under such conditions, the nearest instance being the rails referred to early in the Paper. The Author formed the impression, when examining the broken portions of those rails, that the transverse cracks had been caused under brake-action, but he was informed that the rails were not subject to brake-action. Thus the matter rested for the time, but later in his investigations, when classifying the various "situations," he thought it necessary to place the effects due to "starting" under a distinct class; remembering the broken rails and their peculiar features, he made a point of ascertaining their exact position, thinking that, although they had not been under brake-action as he had first judged, yet their condition might have been caused by the skidding of wheels in starting. The plan of the line and station when examined showed that the two rails had occupied just such a position, being nearly at the end of the down platform, where the locomotives of stopping trains would be at the time of re-starting.

In the event of its being found impossible to make a grade of steel that will entirely resist the induction of flaws, the point then to be determined is—given the class of steel found most suitable under all-round conditions of service—how long can such be used under the various classes of "situation"? The Author considers that the most practical plan will be to ascertain the amount of metal which can be safely worn off the head of a rail before deterioration becomes of moment and to judge the life of a rail accordingly. This problem is perhaps the crux of the whole subject from the engineering point of view. It will certainly be much wiser to judge by the amount of metal which can be worn off safely, rather than from the usual practice of judging by the amount of metal remaining. This latter may lead to a very erroneous estimate as to the fitness of a rail for further use, as its head, although outwardly still in good condition and of sufficient substance, may in reality be seriously weakened internally through undetected flaws.

If it be found that even with the most suitable grade of steel only a certain amount of metal can be worn off the head of a rail before the remaining portion becomes deteriorated (doubtless, too, the amount of wear permissible will vary according to the several classes of "situation" under the conditions of which it is worn off), then it becomes a very important matter in the designing of new bull-headed rails only to provide a reasonable and suitable thickness of metal for wearing purposes. The mere piling-up of the metal in the bull-head may be carried too far (there appears to

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have been a tendency in this direction already), which, in course of time, may be found to be very misleading, as, if the original depth of the head be exaggerated, such rails may become treacherous, owing to the development of flaws, while the head still remains of substantial dimensions. If this prove ultimately to be the case the outlay and interest on the extra capital represented by the superadded weight will have been lost.

The Author would prefer to see some of the increase of weight now being so widely adopted for new rails, made use of in the direction of increasing the depth of the rail section, say ½ inch, for example, his view being that in the event of flaws being induced in the rail-top yet they would not develop or eat their way down into the head so readily if the deflection of the rail were lessened, as it would be very considerably, by even a slight increase in the depth of the section. When a flaw or crack is once started on the surface, its rate of development is undoubtedly affected by the degree of deflection produced by passing loads. With a deeper rail section the overturning or canting action of the tire-flanges against the inside of the rail-head would be rather more severe on the chairs and keys, but a moderate increase of depth should not necessitate any alteration in the form or weight of the chairs already in use.

The question of additional rigidity of the road comes into account, and how it would affect the wear and tear of the rolling stock, possibly an error might be made in having the line too unyielding. These observations are merely suggestive, being offered by one who has not had the opportunity of gaining experience of permanent way.

The question of the flexibility of the rail line naturally leads to the matter of rail-joints. The behaviour of some rail-joints was tested in comparison with the solid rail, and the results showed that with the older pattern, or ordinary fish-plates, *Fig. 24*, the rail is only slightly supported by the joint; in fact, the fish-plates may be looked upon as acting merely as side ties keeping the ends of rail in position opposite each other, and preventing their spreading. The deflection increases enormously with a very moderate increase of load. For example, where the solid rail deflected 0·03 inch the joint deflected 0·15 under an increase of load from 5,000 to 12,000 lbs. When the load was increased to 14,000 lbs. the deflection of joint was 0·60 inch, whereas the solid rail only deflected 0·05 inch. From the results of tests upon the deep form of fish-plate, *Figs. 25* and especially *26*, it appeared that the deflec-

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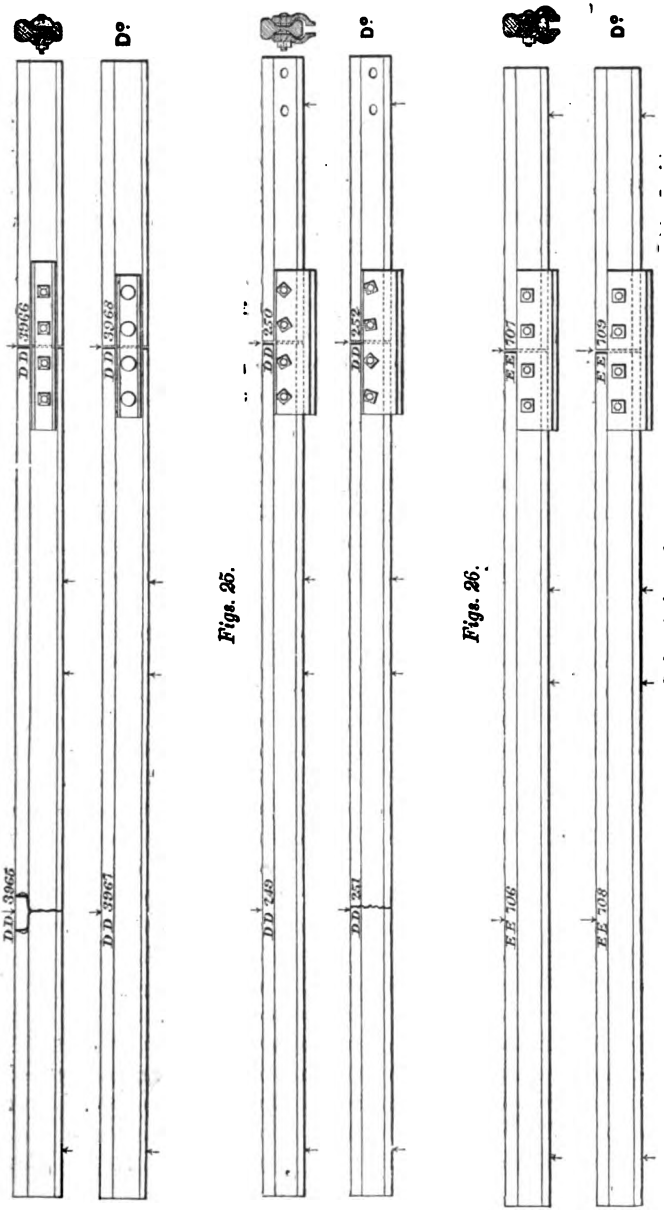

Scale, ¼ inch = 1 foot.

RAILS COUPLED WITH VARIOUS TYPES OF FISH-PLATES FOR TESTING.

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tions under increase of load are very much less than in the shallow or ordinary form. This type of joint is, from the point of view of strength, about as good as is likely to be obtained with a simple form. A supported or rigid joint may not be a desideratum from the point of view of the rolling stock and smooth running of trains. One of the principal features to be kept prominently in view while aiming to make the joint approach as nearly as possible to the solid rail, is to maintain such simplicity that the joint can be easily handled in the road, and, moreover, that it can be kept tight although the rail wears. The advantage of having joints as efficient as practicable is shown by the fact that with broken rails fracture so frequently takes place near the end of the rail, from about the vicinity of the end chair to the second or, at farthest, the third chair from joint. The Author was particularly anxious that a computation might be prepared from the official returns showing the proportions of fractures near ends of rails, and at the same time to deduce the range of distance from end. He considers that fracture near the end undoubtedly points, if not to greater distress of the top surface being produced locally by passing traffic, at least to the greater local flexure of the rail causing such, otherwise uniform, distress to progress or develop more rapidly near the joints.

The microscope is undoubtedly of very great interest for revealing the nature of deterioration, but the Author has preferred to treat the investigation strictly upon mechanical lines as more applicable for practical working, deeming it best, moreover, to leave the treatment of the subject from that point of view to those who have special experience in microscopical investigation.

The chemical analysis is, in the Author's estimation, more properly included in the province of the steel-maker, to determine thereby the best method of obtaining given results; it is distinctly the province of the engineer, however, to determine the grade of material best adapted for each particular purpose and thereupon to specify sufficiently rigid requirements to be fulfilled, under suitable mechanical tests, and finally, before accepting the material, to see that equivalent results are honestly obtained. It is judicious and only fair to allow as much scope to the manufacturer as possible in the conduct of his work, rather than to hamper him by specifying not only mechanical tests but the chemical composition as well, running the risk thereby of the one being antagonistic to the other, tending in practice to prevent advance and improvement in the methods of manufacture.

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While not advising the stipulation of a hard and fast line of chemical composition, the services of the analyst will be highly useful in determining the chemical composition of such rails as have been found by searching mechanical tests to remain free from flaws after long service, while the corresponding results of the mechanical tests are embodied in the specification for imitation or reproduction, the results of the analysis could be transmitted to the manufacturer as useful data to guide him in the endeavour to reproduce a similar grade of steel. The composition of steel being such a complex question, the steel-melter is as a rule better able to determine the best proportions or balance to be maintained relatively between the several components.

The Author endeavoured a few years ago to persuade a firm of steel-makers to have a few ingots of nickel steel rolled into rails for the purpose of a practical trial. The suggestion was scouted owing to extra cost, but the Author still considers it well worthy of trial. Although initially more expensive (only low percentages of nickel were in view) if the steel behaved under the severest conditions in such a way that simply a portion of the metal was worn away while the rest remained in as good a condition as when new, that is, without any flaws being induced; then he thought that it might be deemed feasible by railway engineers to employ such a class of steel even at an increased first cost. Whereas simple or carbon steel is so very susceptible to the rapid spreading of any flaw when once present, an alloy steel may be found to resist the development of such flaws in a much higher degree. This end may, however, be found obtainable in other directions, at more practical rates as to cost, possibly by chromium or manganese; but he has had no personal experience to enable him to offer any results.

More definite information as to the duty performed by worn rails is very desirable in connection with further investigation; probably the fairest standard is the amount of traffic or tonnage passed over any rail, which seems better and more readily obtainable than reckoning the number of pairs of wheels. Certainly a record should be carefully obtained for each rail selected for purposes of testing.

The Author has recently had the opportunity of carrying out some further experiments upon worn rails from the joint line belonging to the Great Northern and Great Eastern Railways. As the rails selected had been in use for a long period, and as the service done by them has been carefully ascertained, their

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behaviour under test is of special interest. Six rails were taken from down line between 147 miles 510 yards and 147 miles 883 yards near Sturton, between Sykes Junction and Stowe Park; 80 lbs. per yard when laid. They were made by the Ebbw Vale Company, and were laid in February, 1873, and taken out July, 1897. The line was straight, on a falling gradient of 1 in 400, and was not subject to brake action. The tonnage computed to have passed over these rails during the 24 years 4 months is set down as 57¼ millions. The inverted tests of these rails show that hardening of the top surface and consequent deterioration had distinctly set in. An additional test was made in the inverted direction, upon a spare portion of each rail after annealing; in five cases out of the six the rails then behaved quite satisfactorily, bending freely although the worn head was placed under tension. In the case of the remaining rail the annealing did not restore it, as it snapped at rather less deflection than before annealing, owing doubtless to some local irregularity. The average weight of these six rails when removed was 77 lbs. per yard.

Six other rails were also selected for experimental investigation at the same time. They were taken out of the up line of the same railway from between 103½ miles to 103⅞ miles, near Misterton; 80 lbs. per yard. They were made by Steel, Tozer and Hampton, and were laid in April and May, 1880, and taken out July, 1897. The line was straight and level, and not subject to brake action. The tonnage computed to have passed over these rails is set down as 50⅓ millions. The average weight of these six rails when removed was 76·58 lbs. per yard. The results of testing showed that there was no appreciable deterioration in any way of this group of six rails. The life is shorter than the other group, being 17 years 2 months. The annealing has had a softening effect upon these rails also, the inverted annealed portions bending more freely than the corresponding ones unannealed. There was not sufficient length in the rails to permit of a fourth bending test, otherwise the Author would have tested an annealed portion in the normal direction also, so as to bring out the degree of softening of the steel quite apart from the effects due to wear or traffic.

In conclusion, the Author is fully conscious that much remains to be added upon such a complex subject; he has felt how impracticable it is to treat it with anything like completeness. Moreover, it must be borne in mind that he has endeavoured rigorously to set forth only what he has personal knowledge of;

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he has therefore not made any search through outside channels to embody the views or experiences of others.

The Paper is accompanied by drawings, from which the Figures in the text have been prepared; and by twenty-five tabulated Reports upon tests of the rails dealt with in the Paper, which may be consulted at the Institution. Four of the Tables, showing the method of reporting the results, are reproduced in Appendix II.

[APPENDIXES.

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APPENDIXES.

APPENDIX I.

ABSTRACT OF REPORT BY AUTHOR ON RAILS ALLUDED TO IN PAPER, DATED *28th November*, 1895.

Two pieces of fractured rail were received and were cut up into specimens prepared upon the standard system, which comprised a tensile or pulling specimen out of the top and one out of the bottom of each piece of rail, also a small specimen out of the head of one of the rails for testing under thrusting stress, which was also used for determining the specific gravity.

The results of pulling tests of the steel in the bottom of the rail showed a mean tensile strength of 94,127 lbs. per square inch, together with contraction of area at fracture of 30·6 and 37·1 per cent. and ultimate extension of 18·4 and 19·9 per cent. respectively (taken in a length of 10 inches). The steel is of a good quality, and cannot be considered too hard, as it maintains proportionate ductility.

Taking this data as being the original quality of the steel, the top of the rail would under normal conditions approximate very nearly to the same. There are differences arising from the amount of work upon the steel in rolling, difference in temperature owing to the varying section, etc., but for the present purposes these need not be taken into account.

The results of the test-specimens prepared from the top of rail in each case showed a great difference in the behaviour of the steel. One specimen broke with a tensile stress of 88,840 lbs. per square inch, which is not only a falling off in strength, but the ductility has almost vanished, the contraction at fracture being only 5·0 per cent. and ultimate extension 4·37 per cent. There is no actual flaw visible, but there is a distinct difference in the texture or granular appearance of the fracture, showing the steel to have been hardened adjacent to the rail surface and gradually altering in character towards the web portion.

Examining next the results of another specimen from the top of the rail, still further light is thrown upon the question of the change which has taken place in the steel, caused by the action of trains travelling on it. The tensile strength has fallen seriously; this is explained by presence of a flaw—an induced flaw—which has penetrated from the surface of the rail into the test-specimen, causing it to fracture at an abnormally low stress—a striking proof of the detrimental effect upon steel of even the most minute flaw or crack. The penetration of this particular flaw, relatively to the area of the specimen, is insignificant; but its effect on the strength, as already mentioned, is very serious. It is described as an induced flaw; by this we mean that it had not been in the steel originally. Its surface and texture, and, moreover, its direction, being across the rail, shows that it is not a scab or roll mark.

The rail appears to have been gradually hardened under the action of the traffic, more especially on the immediate skin or surface, until the steel thereon cracked under the upward flexion of the rail in the regions just over the chairs. Or these minute cracks may have been induced by the severe action of the brakes on trains, so to speak, tearing up or disintegrating the surface of the steel.

In whichever way these minute flaws were originated or induced, experience

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indicates that they will inevitably go on extending or deepening under working conditions.

Special attention is directed to the original fracture, shown at the left-hand end of rail A, which has broken from the surface downwards. In other words, the bottom of the rail has been in compression and not in tension, as proved by the detached portion, which shows a typical fracture, and wherever it occurs it is invariably from the side in compression.

Whether this be the original or primary fracture of the rail or not, the present investigations indicate that the rail failed in this manner, and as the outcome of a flaw or flaws which had been set up and had gradually penetrated downwards from the surface of the rail.

The small specimen tested under thrusting stress also illustrates the difference in the hardness of the steel in the rail-top, as under pressure it has expanded far more on the under portion than at the top, where the surface of the rail had been removed only sufficient to make the end of the specimen true. The exterior surface also shows, by the original polish being less disturbed, that there is a hard skin on the top surface.

Suggestions for future consideration.

It appears a question of great moment to determine, as far as practicable and at an early date, at what period in the life of a rail does this disintegrated or cracked surface arise? Does a hard steel suffer more rapidly and is it more sensitive to the detrimental action of such minute flaws? Is it safe to judge the length of life of a rail by the amount or stage of wear it has reached? Thus a soft rail may be comparatively safe although the section be reduced considerably as compared to a harder steel. Could not a standard or ideal quality of steel for a rail be arrived at now by a series of experiments; not upon new rails, but deduced from rails of known life and behaviour, taken up out of various tracks for experimental purposes?

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APPENDIX II.—

RESULTS OF EXPERIMENTS TO ASCERTAIN THE RESISTANCE TO DEFLECTION AND SET,

Distance between supports, 5 feet;

Description.	Test No.	Weight per Yard.	Stress in Lbs.; Deflection 20,000.	22,000.	24,000.	26,000.	28,000.	30,000.	32,000.	34,000.	36,000.	38,000.	40,000.	42,000.
	D D	Lbs.												
Tested in Normal direction, 1873, G.N.R.	3686	71·87	0·11	0·13	0·15	0·17	0·19	0·21	0·23	0·25	0·33	0·46	0·65	0·77
			Set	..	..	..	..	*0·00*	..	..	..	..	*0·35*	..
Inverted ditto .	3687	71·87	0·11	0·12	0·14	0·16	0·18	0·21	0·24	..	..	..	..	..
			Set	..	..	..	..	..	..	..	..	..	..	..
Normal direction, 1874, G.N.R.	3691	75·00	0·11	0·13	0·15	0·18	0·21	0·31	0·47	0·70	0·95	1·24	1·64	2·15
			Set	..	..	..	..	*0·11*	..	..	..	..	*1·34*	
Inverted ditto .	3692	75·00	0·10	0·11	0·13	0·15	0·19	0·25	0·37	0·55	0·76	..	..	..
			Set	..	..	..	..	*0·07*						
Normal direction, 1874, G.N.R.	3696	73·12	0·11	0·13	0·15	0·17	0·19	0·21	0·32	0·64	0·98	1·34	1·84	2·47
			Set	..	..	..	..	*0·00*	..	..	..	..	*1·54*	..
Inverted ditto .	3697	73·12	0·11	0·13	0·15	0·18	0·21	0·26	0·34	0·52	0·77	1·09	..	..
			Set	..	..	..	..	*0·07*						
Normal direction, 1874, G.N.R.	3701	74·12	0·11	0·13	0·15	0·17	0·18	0·20	0·22	0·24	0·26	0·28	0·33	0·42
			Set	..	..	..	..	*0·00*	..	..	..	..	*0·05*	..
Inverted ditto .	3702	74·12	0·11	0·13	0·14	0·16	0·18	0·20	0·22	0·25	0·28	0·32	0·37	0·45
			Set	..	..	..	..	*0·00*	..	..	..	..	*0·09*	
Normal direction, 1875, G.N.R.	3955	74·50	0·11	0·12	0·14	0·16	0·17	0·19	0·22	0·27	0·39	0·59	0·81	1·04
			Set	..	..	..	..	*0·00*	..	..	..	..	*0·55*	..
Inverted ditto .	3956	74·50	0·11	0·13	0·15	0·17	0·20	0·25	0·31	0·41	0·56	0·72	..	..
			Set	..	..	..	..	*0·05*						
Normal direction, 1875, G.N.R.	3960	74·75	0·11	0·12	0·14	0·16	0·18	0·20	0·22	0·27	0·38	0·56	0·77	1·02
			Set	..	..	..	..	*0·00*	..	..	..	..	*0·49*	..
Inverted ditto .	3961	74·75	0·12	0·13	0·15	0·17	0·19	0·22	0·26	0·32	0·45	0·62	..	..
			Set	..	..	..	..	*0·00*						

Initial stress, 5,000 lbs. The rails upon which the tests were
These rails were all made by the Railway Steel and Plant

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TABLE I.

UNDER A GRADUALLY INCREASED BENDING STRESS OF SIX PIECES OF WORN STEEL RAIL.

load applied at centre.

and Set, 44,000.	46,000.	Inch, 48,000.	50,000.	at 52,000.	54,000.	56,000.	58,000.	60,000.	62,000.	64,000.	Stress. Elastic.	Ultimate.	Ratio of Elastic to Ultimate.	Deflection. At 40,000 lbs.	Ultimate.	Remarks.
											Lbs.	Lbs.	Per cent.	Inch.	Inch	
1·03	1·33	1·68	2·05	2·62	3·17	3·78	5·02	..	..	..	35,000	59,640	58·7	0·65	6·0	Removed uncracked.
..	..	..	*1·66*													
..	..	..	..	..	..	..	..	..	..	..	30,000	33,980	88·3	..	0·28	Snapped, slight flaws.
2·64	3·39	4·40	..	..	..	..	..	..	..	..	28,500	49,480	57·6	1·64	6·0	Removed uncracked.
..	..	..	..	..	..	..	..	..	..	..	27,700	37,590	73·7	..	1·00	Snapped, no visible flaw.
3·31	4·42	6·47	..	..	..	..	..	..	..	..	30,500	48,355	63·1	1·84	7 0	Removed uncracked.
..	..	..	..	..	..	..	..	..	..	..	29,700	39,285	75·6	..	1·31	Snapped, no visible flaw.
0·55	0·74	0·98	1·33	1·64	2·02	2·57	3·14	4·01	5·46	..	39,800	63,670	62·5	0·33	7·0	Removed uncracked.
..	..	..	*0·95*													
0·58	0·71	0·88	..	..	..	..	..	..	..	..	37,900	40,080	78·8	0·37	0·89	Snapped, no visible flaw.
1·33	1·62	2·04	2·56	3·15	3·96	4·84	..	..	..	..	33,700	57,705	58·4	0·81	5·62	Snapped.
..	..	..	*2·16*													
..	..	..	..	..	..	..	..	..	..	..	29,800	39,980	74·5	..	0·89	Snapped.
1·28	1·60	2·01	2·46	3·02	3·74	4·82	6·80	..	..	..	33,900	59,770	56·7	0·77	9·0	Removed uncracked.
..	..	..	*2·08*													
..	..	..	..	..	..	..	..	..	..	..	30,500	39,990	76·3	..	0·81	Snapped.

made are illustrated in *Figs. 9*; they were all 12 feet long.
Company, Manchester. For tensile tests, see Table IV.

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APPENDIX II.—

RESULTS OF EXPERIMENTS TO ASCERTAIN THE RESISTANCE TO DEFLECTION AND

Distance between supports, 5 feet;

Description.	Test No.	Dimensions.		Weight per Yard.	Stress in Lbs.; Deflection										
					30,000.	32,000.	34,000.	36,000.	38,000.	40,000.	42,000.	44,000.	46,000.	48,000.	50,000.
	DD.	Inches. Depth.	Web	Lbs.											
Worn rail; 80 lbs. main line; 62 and 63 miles; 23 years' service	3,885	5·00	·65	77·62	0·20	0·22	0·24	0·28	0·41	0·62	0·87	1·09	1·41	1·86	2·36
					Set	..	..	..	..	*0·34*	..	..	..	..	*1·98*
Ditto, tested inverted	3,886			77·62	0·21	0·23	0·25	0·29	0·37	0·59	0·80	1·09	1·35	1·69	2·00
					Set	..	..	..	..	*0·31*	..	..	..	..	*1·63*
New rail	3,887	5·50	·68	85·41	0·18	0·19	0·21	0·22	0·24	0·26	0·28	0·31	0·39	0·55	0·70
					Set	..	..	..	..	*0·00*	..	..	..	..	*0·40*
Ditto, tested inverted	3,888			85·41	0·17	0·19	0·21	0·23	0·25	0·28	0·30	0·35	0·42	0·54	0·72
					Set	..	..	..	..	*0·00*	..	..	..	..	*0·42*
Worn rail; 85 lbs.; in road 5 years, with heavy wear	3,889	5·48	·68	84·25	0·17	0·19	0·20	0·21	0·23	0·24	0·26	0·27	0·29	0·33	0·41
					Set	..	..	..	..	*0·00*	..	..	..	..	*0·10*
Ditto, tested inverted	3,890			84·25	0·16	0·17	0·19	0·20	0·22	0·24	0·26	0·29	0·32	0·36	0·46
					Set	..	..	..	..	*0·00*	..	..	..	..	*0·17*
Worn rail; 82 lbs.; 10 years' service	3,891	4·95	·66	75·00	0·21	0·22	0·24	0·26	0·28	0·31	0·35	0·43	0·56	0·72	0·92
					Set	..	..	..	..	*0·02*	..	..	..	..	*0·55*
Ditto, tested inverted	3,892			75·00	0·20	0·22	0·24	0·25	0·27	0·31	0·36	0·46	0·58	0·73	0·92
					Set	..	..	..	..	*0·02*	..	..	..	..	*0·53*
Worn rail; exposed to brake action	3,893	4·86	·66	74·70	0·23	0·25	0·27	0·34	0·48	0·64	0·84	1·07	1·31	1·58	1·94
					Set	..	..	..	..	*0·33*	..	..	..	..	*1·52*
Ditto, tested inverted	3,894			74·70	0·22	0·26	0·30	..	..	..	..	..	..	..	..
					Set	..	..	..	..	..	..	..	..	..	..

Initial stress, 5,000 lbs. The rails upon which
For tensile

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TABLE II.

SET UNDER A GRADUALLY INCREASED BENDING STRESS OF FIVE STEEL RAILS.

load applied at centre.

and Set.		Inch		at								Stress.		Ratio of Elastic to Ultimate.	Deflection.		Remarks.
52,000.	54,000.	56,000.	58,000.	60,000.	62,000.	64,000.	66,000.	68,000.	70,000.	72,000.	74,000.	Elastic.	Ultimate.		At 40,000 lbs.	Ultimate.	
												Lbs.	Lbs.	Per cent.	Inch.	Ins.	
2·84	3·55	4·39	5·66	7·15	..	..	..	..	..	..	..	35,700	60,780	58·7	0·62	8·0	Removed uncracked
2·44	2·89	3·40	3·98	..	..	..	..	..	..	..	..	35,800	58,240	61·5	0·59	4·19	Snapped
0·84	1·06	1·26	1·47	1·69	1·92	2·26	2·58	2·98	3·41	4·02	4·82	44,300	78,840	56·2	0·26	8·0	Removed uncracked
..	..	..	..	*1·31*	..	..	..	..	*2·93*								
0·86	1·01	1·19	1·37	1·56	1·78	2·04	2·31	2·59	2·95	3·33	3·79	43,500	77,350	56·2	0·28	6·5	Removed buckling
..	..	..	..	*1·18*	..	..	..	..	*2·49*								
0·48	0·59	0·70	0·84	0·99	1·14	1·34	1·53	1·73	1·97	2·22	2·49	47,800	86,710	55·1	0·24	8·0	Removed uncracked
..	..	..	..	*0·61*	..	..	..	..	*1·50*								
0·52	0·62	0·73	0·85	1·00	1·11	1·27	1·45	1·60	1·84	2·05	2·26	47,800	88,130	54·2	0·24	6·5	Removed buckling
..	..	..	..	*0·62*	..	..	..	..	*1·38*								
1·08	1·33	1·60	1·90	2·30	2·62	3·09	3·60	4·34	5·46	6·90	..	40,000	73,130	54·7	0·31	8·0	Removed uncracked
..	..	..	..	*1·81*	..	..	..	..	*4·82*								
1·10	1·33	..	..	..	..	..	..	..	..	..	..	40,000	55,260	72·4	0·31	1·44	Snapped
2·35	2·80	3·32	4·17	5·15	..	..	..	..	..	..	..	35,400	61,440	57·6	0·64	7·0	Removed uncracked
..	..	..	..	*4·57*													
..	..	..	..	..	..	..	..	..	..	..	..	31,500	35,400	89·0	..	0·36	Snapped; slight flaw

the tests were made are illustrated in *Figs. 10.*

tests, see Table III.

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APPENDIX II.—TABLE III.

RESULTS OF EXPERIMENTS TO ASCERTAIN THE ELASTIC AND ULTIMATE TENSILE STRENGTH, &c., OF SPECIMENS PREPARED FROM FIVE STEEL RAILS.

Test No.	Description.	Original		Stress.		Ratio of Elastic to Ultimate.	Contraction of Area at Fracture.	Length 10 Inches. Extension, Sets, at—				Appearance of Fracture.
		Diameter.	Area.	Elastic per Square Inch.	Ultimate per Square Inch.			60,000 lbs. per Square Inch.	70,000 lbs. per Square Inch.	80,000 lbs. per Square Inch.	Ultimate.	
DD		Inch.	Square Inch.	Lbs.	Lbs.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
	Worn rail.	Turned										
3898	Top	1·128	1·000	44,900	78,920	56·9	13·4	3·24	6·04	..	13·5	Granular, slight defect
3899	Bottom	1·128	1·000	45,900	81,030	56·6	37·8	3·07	5·69	13·7	22·4	50% silky, 50% granular (fine)
	New rail.											
3901	Top	1·128	1·000	43,200	84,870	50·9	37·8	2·01	3·52	7·07	19·4	80% silky, 20% granular
3902	Bottom	1·128	1·000	47,000	88,780	52·9	42·6	1·52	2·98	5·55	18·2	Silky
	Worn rail.											
3904	Top	1·128	1·000	52,500	97,810	53·7	8·4	0·84	1·70	2·93	7·5	Granular
3905	Bottom	1·128	1·000	49,200	95,990	51·3	41·9	1·18	2·27	3·87	17·2	90% silky, 10% granular (very fine)
	Worn rail.											
3907	Top	1·128	1·000	52,500	99,580	52·7	16·7	1·10	2·13	3·47	15·6	Granular, slight defect
3908	Bottom	1·128	1·000	54,300	100,510	54·0	30·6	1·05	2·04	3·37	17·2	20% silky, 80% granular
	Worn rail											
3895	Top	1·128	1·000	40,700	81,490	49·9	39·9	2·58	4·70	10·4	21·0	85% silky, 15% granular
3896	Bottom	1·128	1·000	44,200	84,470	52·3	39·9	2·43	4·34	8·50	21·1	85% silky, 15% granular

For bending tests, see Table II.

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APPENDIX II.—Table IV.

Results of Experiments to Ascertain the Elastic and Ultimate Tensile Strength, &c., of Specimens prepared from Six Pieces of Worn Steel Rail.

Test No.	Description.	Original.		Stress.		Ratio of Elastic to Ultimate.	Contraction of Area at Fracture.	Length, 10 inches. Extension, sets, at—				Appearance of Fracture.
		Diameter.	Area.	Elastic per Square Inch.	Ultimate per Square Inch.			50,000 lbs. per Square Inch.	60,000 lbs. per Square Inch.	70,000 lbs. per Square Inch.	Ultimate.	
D D.	Piece marked.	Inch. turned	Square Inch.	Lbs.	Lbs.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
3688	Top	1·128	1·000	41,000	79,910	51·3	45·9	1·11	2·59	5·16	19·9	80% silky, 20% granular (fine).
3689	Bottom	1·128	1·000	43,500	81,410	53·4	39·2	1·26	2·66	5·14	21·7	60% silky, 40% granular (fine).
	Piece marked..											
3693	Top	1·128	1·000	34,300	50,380	68·1	5·0	2·40	..	..	2·5	Granular, coarse and irregular.
3694	Bottom	1·128	1·000	37,500	69,280	54·1	30·6	2·60	5·34	..	19·7	25% silky, 75% granular, slightly unsound.
	Piece marked...											
3698	Top	1·128	1·000	37,900	67,670	56·0	10·1	1·99	4·21	..	7·8	8% silky, 92% granular.
3699	Bottom	1·128	1·000	39,400	69,720	56·5	20·7	2·46	4·90	..	16·9	12% silky, 88% granular, slightly unsound.
	Piece marked....											
3703	Top	1·128	1·000	52,600	86,720	60·7	39·2	0·00	1·62	3·30	20·6	55% silky, 45% granular.
3704	Bottom	1·128	1·000	54,000	87,390	61·8	40·6	0·00	1·60	3·41	20·7	60% silky, 40% granular.
	Piece marked....											
3706	Annealed from top	1·128	1·000	51,900	85,760	60·5	45·9	0·00	1·87	3·68	18·3	80% silky, 20% granular (very fine).
3707	Annealed from bottom	1·128	1·000	49,900	86,480	57·7	47·2	0·05	1·90	3·70	20·2	85% silky, 15% granular (very fine).
	Worn rail marked!!!!											
3957	Top	1·128	1·000	41,000	79,510	51·6	8·4	1·14	2·31	4·10	7·3	5% silky, 95% granular.
3958	Bottom	1·128	1·000	41,900	80,530	52·0	33·5	1·53	2·96	5·46	19·7	35% silky, 65% granular.
	Worn rail marked!!!!											
3962	Top	1·128	1·000	38,400	75,800	50·7	45·9	1·80	3·52	7·23	21·6	Silky.
3963	Bottom	1·128	1·000	45,000	77,330	58·2	44·6	1·77	3·38	6·49	22·8	Silky.

For bending tests, see Table I.

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(*Paper No. 3153.*)

"On Photo-micrography of Steel Rails."

By Sir WILLIAM CHANDLER ROBERTS-AUSTEN, K.C.B., F.R.S., Assoc. Inst. C.E.

THE following brief statement of the principles which guide photo-micrography of steel rails is offered by the Author, with a view particularly to elicit information on the interesting and important question of the practicability of deducing an "ideal" or standard quality of steel rail from the behaviour of rails which have been already abundantly tested in actual use.

For micrographic purposes steel is viewed as if it were a rock with various minerals distributed through it, and mineralogical names are conveniently adopted for the constituents. Thus, iron free from carbon is called "ferrite," which is left white and brilliant when the polished specimen is treated either with a solution of iodine or an infusion of liquorice. Strong nitric acid also does not attack it, but the use of this re-agent is not to be recommended. "Cementite," another constituent of steel, is a carbide which corresponds to the formula Fe_3C. It remains bright after the polished section of steel is attacked by iodine solution. It is hard, and stands in relief when the steel is polished with the finest rouge on a wheel covered with cloth. Free cementite, however, very rarely occurs in low carbon steels. The carbide usually assumes the form of "pearlite," which is an intimate mixture of ferrite and cementite; it is a very characteristic constituent of steel which has been slowly cooled from a high temperature, and if the steel contains about 0·9 per cent. of carbon, the whole mass will mainly consist of pearlite. It may be either lamellar or granular in structure. It may be coloured dark with iodine solution, and its presence is best revealed when the steel is polished in relief by the method indicated and treated with an infusion of liquorice root in cold water. It consists of lamellæ, which are alternately hard and soft. Hardened steel appears to be composed of "martensite," a system of interlacing

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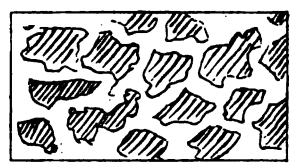
crystalline fibres, which may be coloured by prolonged treatment with an infusion of liquorice.

As regards the structure of a steel rail, information which is most generally useful is afforded by cutting a section in the portion of the rail which it is desirable to examine and treating it in the following way:—The metal is polished with the finest emery on paper, and finally with rouge on a revolving plate covered with wet cloth. It is then rubbed on parchment paper on a soft wood base with an infusion of liquorice root in water. This treatment stains the carbide (pearlite) a dark tint and leaves the ferrite or iron unacted upon. The most useful magnification, generally, is between 100 and 150 diameters. When so examined normal rails consist of patches of the carbide of iron "pearlite" set in "ferrite," as is shown in the appended sketch. But although the structure is common to all rails, the dimensions of the areas of pearlite and ferrite differ greatly. The greater the amount of carbon, as revealed by chemical analysis, the larger will be the area occupied by pearlite. In the presence of much manganese the carbide area is relatively large and the ferrite becomes a mere connecting network enclosing the carbide areas. This is well shown by Figs. 4 and 5, Plate 2, which are the richest in manganese in the series. It is noteworthy that Figs. 1 and 3 contain approximately the same amounts of carbon and of manganese, but their structure is very different. As a general statement it seems safe to conclude that if the ferrite is arranged in comparatively large enclosed polyhedrons, it indicates that the rail was raised to too high a temperature before it was rolled. The strength and extensibility of the rail increases as the size of the grain diminishes. It is also an established fact that closely interlocking ferrite and pearlite is the condition which most favours the prolongation of the life of a rail. As regards strength, it may be mentioned that rails, of which Figs. 4 and 5 are microsections, stood the falling-weight test worse than the rest. Fig. 6 represents a rail of exceptional purity which was taken up from the line after 27 years' wear; it only broke under the falling-weight test with a fall of 27 feet. The structure of this rail, as shown in Fig. 6, Plate 2, is quite exceptional.



The shaded portions indicate pearlite.
„ white „ „ ferrite.

In order to obtain further information as to the rails, higher magnification must be resorted to. The rail referred to by

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Mr. Kirkaldy (*ante* pp. 141–146), which was subjected to "skidding" action, presents a fine case of what is known as hammer hardening. The structure of this rail could hardly be explained by the merely mechanical treatment it had received.

The photo-micrographs, shown in Plate 2, have all been taken from central portions of rails. Had they been from external portions, the grain would be smaller and the amount of carbide somewhat less.

Reference to microflaws, altered surfaces of rails and to internal slag flaws, have been omitted, as it is desirable to direct the discussion of this subject mainly to the question of the relative areas of pearlite and ferrite. For this reason, the consideration of the subject had in the present notes been restricted to the narrowest possible limits, and the foregoing statements were not offered in order to express any particular views, but merely to introduce a subject which has not as yet been brought to the attention of the Institution.

The Paper is accompanied by six photographs and a drawing, from which Plate 2 and the Figure in the text have been prepared.

DISCUSSION.

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Discussion.

Mr. W. H. PREECE, C.B., President, said it was his pleasing duty to propose a vote of thanks to the Authors of the two Papers for having brought before the Institution a subject so extremely interesting and so unquestionably valuable. It must be a matter of gratification to many of the old members to find that the pioneer work of their old friend David Kirkaldy was being carried on so satisfactorily and so ably by his son. The Papers were both highly scientific in their aim, but the one was essentially mechanical and experimental, and the other a searching into the depths of things with one of those mental eyes which Science had imparted to observers. Prof. Sir William Roberts-Austen had not only shown the composition of steel as it was, but, in his Paper, he had gone far enough to indicate the history of that steel, and to read the process of cementation, and all the changes brought about by temperature in its various stages, since its preparation. The subject had been very brilliantly and beautifully put before the members, and he was sure they would with acclamation carry a resolution giving a vote of thanks to both the Authors. Mr. Preece.

Sir WILLIAM C. ROBERTS-AUSTEN, K.C.B., exhibited upon the screen the following photo-micrographs, to illustrate the various forms in which carbon might occur in iron:—(1) A variety of iron containing about $\frac{4}{10}$ per cent. of carbon, which had been slowly cooled. The magnification was about 800 diameters. The white parts represented the ferrite, and the dark portions the grains of pearlite; that was, the alternate layers of ferrite and of carbide, Fe_3C, which constituted the pearlite. Of the few round photographs, that was the only one which in any way represented a steel rail, but he thought it would be well to show the mode of existence of the carbon under varied thermal treatment, in order that it might be seen how complex the question really was. (2) Nearly the same variety of steel, but, instead of being slowly cooled, it had been quenched from a temperature of 750° C., and the carbide, instead of existing as pearlite in alternate laminæ of pearlite and carbide, was aggregated into knotty lumps, to which the name Troostite had been given. As far as he knew, that variety of carbide seldom occurred in a steel rail. (3) A variety of steel which contained some 1·2 per cent. of carbon, and had been very slowly cooled. The slide showed the mass of the Sir William Roberts-Austen.

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Sir William Roberts-Austen.

material made up of pearlite, *i.e.*, alternate bands of carbide and of ferrite, but there was a mass of carbide concentrated into a broad band which would be known as banded cementite. (4) The same steel, quenched from a bright red heat, and exhibiting the needle-like aggregation of the carbon known as martensite. (5) The same steel, quenched from a bright red heat and tempered. (6) A variety of steel containing 1·6 per cent. of carbon heated to bright redness, and quenched in iced brine. It was seen how totally different the aggregation of the carbide was from any of the preceding slides. To that variety of carbide the French had given the name of Austenite. An exceedingly good rail, which Mr. Kirkaldy had been kind enough to send him, was shown in section, in Fig. 15, Plate 3. In beginning the micrographic examination of a rail, it was well to coat one side of such a section with varnish, and to pickle the whole of the rail section in sulphuric acid. The result was that it could be seen how certain of the materials were distributed, and the rails varied widely in the way they were acted upon by sulphuric acid. Rails rich in manganese usually showed, when treated by sulphuric acid, a very minute structure, considerably finer than the rail in question, but, if the section was carefully examined it would be seen that round the outer edge there was a widely different structure from that which occurred in the centre. In the same way the drawing out of the web by rolling had extended certain portions of the material, some of which were slag. The edge of rail section showed at once what portions of the rail best deserved micrographic examination, and the sections he was about to throw on the screen were taken respectively from the points marked A, B, C, D, E, F, G, and H on Fig. 15, Plate 3, which is a photograph of the entire rail section. A and B were micrographs taken from the extreme upper corner of the running surface of the rail shown in Fig. 15 and they indicated the peculiar structure which was obtained by what Mr. Kirkaldy called "hammer-hardening." C, Fig. 9, was another section taken very near the running surface, showing broad bands of ferrite enclosing masses of pearlite. D, Fig. 10, was a specimen taken near the centre of the head. E, Fig. 11, was from the outer portion of the centre of the web, and in this case the ferrite existed in the form of longish bands instead of the network which enclosed the pearlite. That rail, so far as his experience went, was somewhat exceptional, as he had not met with another case in which the ferrite had been so much extended as in that particular case; the rail was a very good one. In F, Fig. 12, the elongation of the ferrite bands was still more

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marked. G, Fig. 13, was a section taken near the bottom of the rail; the area of pearlite had become larger, and the ferrite restricted to narrow, mesh-like bands, while in H, Fig. 16, extreme base of the rail, the under surface was shown. The long line structures had entirely disappeared, and the mesh-like structure reappeared. Fig. 17 gave magnification of about 850 diameters of the centre of a rail. It showed that the carbide, which under lower magnification was very small patches, resolved itself into much the same banded alternations of black carbide and white ferrite as seen in the first slide. The upper layer of a rail was often very thin and might be easily removed by planing; it differed from the rest of the rail beneath it. Sir William Roberts-Austen.

Mr. W. G. KIRKALDY exhibited photographs upon the screen illustrating the minute hair cracks referred to in the Paper, transversely to the length of the rail, and symmetrically arranged at practically equal distances apart, Figs. 18 and 19, Plate 3. The rail had been subjected to skidding action, and was very hard on the surface; no tool could be found to cut it at the top surface, so that it was cut from the rear and snapped off. Where trouble had arisen it was evidently due to some of those cracks which had developed while the rail was in the line. Although the bulk of the rail might not be very much damaged there was a risk of some of the cracks penetrating more deeply. He also illustrated a specimen, Fig. 20, prepared from the head of the rail and tested by crushing. When it was prepared in the lathe there was only a slight amount taken off the top surface to true it. At that time the cracks could not be seen by the eye, but they had developed under pressure. The cracks were all transverse to the length of the rail, as induced flaws were always found to occur. Another photograph, Fig. 21, illustrated a rail from the L. B. & S. C. line, exhibiting the cracks in a very symmetrical manner. It was discovered owing to a piece having scaled off. Whether that was an original defect in the rolling of the rail it was difficult to state positively, but it had all the appearance of being so. There was a specimen on the table which pointed to a surface crack having penetrated vertically downwards, and then turned and worked its way horizontally. Mr. Kirkaldy

Sir LOWTHIAN BELL, Bart., said that Sir William Roberts-Austen had applied the word "famous" to a particular rail, and he believed that was the first occasion on which he had ever heard that appellation applied to a rail, but never in his life had he met with one more worthy of that distinction. The number of rails which were found broken on railways was, as nearly as he Sir Lowthian Bell.

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Sir Lowthian Bell.

had been able to compute, 1 in 3,500. It was remarkable that until the rail referred to early in the Paper gave way no accident had been heard of attended with any serious circumstances. Notwithstanding that piece of statistical knowledge, the fracture of that rail created dismay, not only in the minds of travellers, but in the minds of ironmasters themselves; and one of the first attempts to cure it was to increase the size of the head of the rail, the propriety of which, he understood, Mr. Kirkaldy doubted. He also was inclined to do so, because if the change referred to by Sir William Roberts-Austen was correct, the longer a rail was exposed to the rolling and percussive action on the line the more brittle it probably would become. With regard to the cracks in the rail, he should like to know, before he proceeded further, to what extent the Author, who had performed all those beautiful experiments, had had an opportunity of comparing the quality of a rail of any particular section, that was, with regard to its composition, its brittleness, or the reverse. He mentioned that, because it was quite easy almost to prove anything by an examination of rails; in fact, the behaviour of rails on the line was so capricious that he found himself always in a position of considerable difficulty in making any very strong assertion in regard to any particular event, because he had found over and over again that the opinion that he came to after a somewhat extensive course of examinations was contradicted by the very next experiment he made. He might perhaps be permitted to say that for 25 years of his life he was a rail manufacturer, and for over 25 years he had been one of the directors of the North Eastern Railway Company, and he naturally took a great interest in a question which at that time did not appear to receive much attention from railway engineers themselves, viz., what was the safe time to allow a rail to remain on the line? For the last 5 years he had been engaged in tabulating all the results of the rails that had been taken up on the North Eastern Railway, and the conclusion he had come to was, as he had said before, first, the great difficulty attending the question; and, secondly, the very contradictory nature of the results obtained. With regard to the cracks, he did not pretend that it was not highly desirable to avoid the existence of those small fissures in the rail, but he was not quite sure that the very prominent importance ought to be attached to their existence which Mr. Kirkaldy had given to them. The top member of the rail when it received the train was put into a state of compression, and the effect of that compression, in his opinion, would tend to seal up

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the small fissures. He was very anxious to ascertain experimentally how far the fissure—not in iron or steel—was detrimental to stability and strength, and for that purpose he had experimented on slips of plate glass, one or two of which he had on the table. These were supported on bearings 10 inches apart, and weights were applied to a knife-edge resting on the centre of the slip of glass. The glass which was not scratched at all withstood a weight of about 40 lbs. before it broke. He then scratched the glass with an ordinary glazier's diamond and applied a weight, the scratch being on the under side, and the breaking weight was 16 lbs. He then tried another sample, having the scratch on the upper side of the plate, and within a few pounds it was as strong as the glass without any scratch upon it. That was the kind of action which appeared to him was very likely to take place in the case of rails, and he attached very little danger to the fact of passing over a broken rail, and for the same reason, viz., that the two ends of the fractured rail, in point of fact, were supporting each other, and further danger was thus avoided. He did not know whether Sir William Roberts-Austen had been able to connect chemical composition with the separation of steel into those very curious and highly interesting divisions, of which he had given such brilliant examples. If that was the case, then there was no great difficulty. He supposed, first and last, he must have taken a part in the analysis of about ten thousand specimens of rails, for about that number had passed through the laboratory of the North Eastern Railway during the last 15 years. That was about the most perplexing of all the problems he had had to deal with. He had tabulated several hundreds of specimens according to the quantity of metals and metalloids contained in the rail and there was no kind of harmony between weakness and great purity; and on the other side there was no harmony between great purity and great strength. He had, therefore, come to the conclusion that great care was necessary in forming any decision too rapidly on all subjects connected with rails. The catalogue of difficulty was not exhausted in speaking of the rails themselves, for the changing character of the traffic to which they were submitted had also to be regarded. At such a station as Newcastle-on-Tyne, the money receipts were probably twenty times those of many remote agricultural districts. Consequently the wear on the rails was immensely greater in the former, than in the less frequented localities. At the same time it might be from some defect in the laying of rails. Upon one occasion, a breakage of some dozen

Sir Lowthian Bell.

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Sir Lowthian Bell.

or more rails had occurred at a small place called Warcup, near Kirkby-Stephen, which any one conversant with the geography of Cumberland would know was a very remote place, having very little traffic; but, possibly from some fault in the laying, fourteen rails gave way in that place. There had been others equally difficult to account for. He did not know whether it might interest the Institution to have, when the work he was busy with at the present moment was completed, some account of the conclusions to which he had come with regard to the North Eastern Railway. If it should be the wish of the President of the Institution, and with the permission of his colleagues on the Board of the North Eastern Railway, he should be glad to communicate them to the Institution. He hoped to obtain that permission from his colleagues, not only in the interests of railways generally, but in the interests of scientific manufacture. With regard to the manufacturers aiming at any particular constitution of the rails, that was a very much more difficult question. When it was conceived that into a great cauldron about 15 tons or 16 tons of metal were poured, and that in 15 minutes the whole of that metal had been converted into Bessemer steel, it would be seen that it was almost impossible to calculate with any degree of nicety the character of the product. With regard to the ends of rails, Mr. Kirkaldy very properly drew attention to the fact that a particular end of the rail might be imperfectly welded; that was very likely. Unfortunately breaks took place, as was known very well, at parts distant from the end. He had proved one thing with regard to the character of steel as a whole in an ingot, viz., that the rail made from the middle and from the bottom of the ingot was superior in quality to that made from the upper end, and that was precisely what a Bessemer steel manufacturer would expect. The blow-holes, as they were termed, and the scoriacious portions necessarily floated to the top, and in the meantime the steel was becoming more and more viscous in its character, and there was a greater difficulty in such impurities escaping. As a matter of fact, as might be expected, that was the worst part of the rail. He did not know that the plan pursued by railway companies was most likely to overcome the difficulty, for when they bought rails, as they had done, in very large quantities, made from very good material, at the unremunerative price of £3 15*s.* 0*d.* a ton, he thought it would be allowed there was not very much encouragement to the rail-maker to make a very good article.

Mr. Snelus.

Mr. G. J. SNELUS thought it would be very interesting and very important if the chemical analysis of the rails which had been so

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elaborately tested by Mr. Kirkaldy could be given. With that information the members might be able to draw conclusions which they certainly could not without them. He admitted that the mechanical treatment was probably more important than the chemical knowledge of the rails in question; but, at the same time, he thought it was not wise to separate the two subjects; they should go hand in hand in order that the members might have full and complete information to study the question fully. He should like to ask Mr. Kirkaldy if he had had opportunity of observing whether the cracks were developed in flange rails to the same extent as they appeared to be developed in bull-head and double-headed rails; it seemed that the flaws occurred mainly over the chairs. Whether the occurrence of the flaws on the chairs was due to the hammering action there, with the rail being supported as on an anvil, or whether it was that the flaws were due to the action of the wheel when it passed in the middle, between two chairs, causing the head of the rail over the chair then to be in tension was a point which required further investigation; but if it was the case, might it not be that, after all, the flange rail, which was so much in favour with engineers on the Continent and in America, had yet points of advantage over the bull-headed rails, with the numerous anvils which were used to support them? He agreed that it would be probably an advantage to add more to the height of the web of the rail and put rather less matter into the head. He thought that the larger the mass of metal in the head, the more chance there was for the cracks to be developed. Then Mr. Kirkaldy also suggested that it might be advisable to ascertain whether a different chemical composition would stop the development of the cracks, and he suggested that it might be advisable to try an alloy of nickel, or of chromium, or of manganese. Of the three metals mentioned, he thought the chances were decidedly in favour of nickel. He thought there was a good deal yet to be learned with respect to the alloy of nickel and iron. It was known that in the nickel armour-plates, the incipient cracks, which were developed on the impact of the shot, were not developed to nearly the same extent in the nickel plate as they were in the old ordinary steel plate. It might be that the nickel alloy of iron would prevent those flaws in a somewhat similar way to its effect on the armour plate. It was quite true that the expense of the alloy was a point of very great importance. There was no doubt that, in order to produce a nickel alloy which would be of any value at all, at least 20*s.* a ton would have to be

Mr. Snelus.

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Mr. Snelus. added to the cost of the rail. At the same time that 20*s.* extra price might be very well earned, and he thought that experiments in the direction suggested by Mr. Kirkaldy of using a nickel alloy ought to be tried. With respect to the Paper by Sir William Roberts-Austen, he would like to ask whether the Author had ever attempted to obtain a photo-micrograph of a section at right angles to such sections as were shown in Plate 2. He should like to know how deep those masses of ferrite and pearlite went; he supposed it would be possible to measure them. At present all the diagrams that he had seen appeared to be of only one surface. He thought it would be extremely important if they could be examined at right angles to the surface. Photographs of the object to be examined might be taken first, and then a photograph of a carefully-prepared specimen at right angles to that surface. He should like to ask also whether Sir William Roberts-Austen had ascertained whether the flaws found in the heads of rails followed the line of the ferrite or of the pearlite, or whether they cut quite clean through both the components of the metal. He thought these were all questions which were very interesting, and it would be worth while to have some further information about them.

Mr. Ross. Mr. ALEXANDER ROSS exhibited Tables showing chemical analyses of some of the rails referred to in the Paper. Table I proved that a rail did produce different analytical results at different portions along its length. He believed that different results would be obtained from different points, even in the surface of the cross-section of a rail. In any case, the Tables associated the analytical results with the mechanical, and he thought in some instances they offered a warning rather than otherwise.

TABLE I.—AVERAGE ANALYSIS OF TEN DIFFERENT TESTS OF RAILS ALLUDED TO BY THE AUTHOR, *Figs. 1–8.*

	Maximum.	Minimum.	Average.	Difference between Maximum and Minimum.
	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	0·540	0·234	0·464	0·306
Silicon	0·130	0·038	0·109	0·092
Sulphur	0·106	0·065	0·085	0·041
Phosphorus	0·125	0·065	0·083	0·060
Arsenic	0·052	0·026	0·041	0·026
Manganese	0·493	0·300	0·443	0·193
Copper	0·060	0·047	0·053	0·013
Iron	98·826	98·621	98·722	0·205

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TABLE II.—ANALYSIS OF THE EXTREMES OF THE TWELVE WORN RAILS REFERRED TO BY THE AUTHOR AT pp. 163 AND 164.

Mr. Ross.

	Rails taken from Line between Sykes Junction and Stow Park.		Rails taken from the Line near Misterton.	
	Hardest.	Softest.	Hardest.	Softest.
	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	0·382	0·285	0·508	0·368
Silicon	0·029	0·021	0·091	0·050
Manganese	0·414	0·273	0·844	0·621
Sulphur	0·060	0·060	0·063	0·072
Phosphorus	0·126	0·107	0·066	0·053
Arsenic	0·017	0·015	0·023	0·022
Copper	0·046	0·043	0·016	0·016
Iron, by difference	98·926	99·196	98·389	98·798

TABLE III.—ANALYSIS OF RAIL REFERRED TO BY THE AUTHOR AT p. 150.

	Rail Head.	Rail Web.	Rail Bottom.
	Per cent.	Per cent.	Per cent.
Combined carbon	0·340	0·350	0·380
Silicon	0·062	0·054	0·052
Manganese	0·478	0·486	0·446
Sulphur	0·065	0·070	0·080
Phosphorus	0·110	0·118	0·130
Iron, by difference	98·945	98·922	98·912

Table II dealt with rails which gave very good mechanical results, and therefore were very interesting. Table III gave an analysis of the rail referred to by Mr. Kirkaldy as an ideal rail. There again the connection between the mechanical and the chemical results was exceedingly interesting. He was anxious to learn what was the ideal, not only chemically but mechanically, and what tests should be looked for that would produce the best possible rail. He would be interested to know whether the Bessemer process was preferable to the Siemens-Martin process, or to have a comparative statement concerning them. It was desirable to know what was the best process or the best rail, even regardless of price. In two distinct parts of the Paper the Author had asserted his opinion that harder steel rails ought to be used. He would not traverse that opinion, but he had his doubts on the subject. It would be interesting and valuable if that matter were discussed by those thoroughly acquainted with the subject.

Mr. R. PRICE-WILLIAMS considered that the Author had in the Paper valuably supplemented the important and exhaustive re- Mr. Price-Williams.

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Mr. Price-Williams.

searches of his eminent father. Regarding the chemical tests, he was very glad to see on the walls the Tables prepared by Mr. Ross, which supplied, to a great extent, that omission in the Paper. He was quite certain that, having regard to the effects of the hammer hardening caused by the impact of the trains, it was of the highest importance that more light should be thrown on the subject, more especially in relation to the nature of the chemical constituents of the rail. Recent experience in the United States had shown that the low percentages of carbon which engineers were accustomed to in England did not suit the requirements of the traffic in the States, where percentages as high as 0·7 of carbon were, to his knowledge, required in the specifications of recent rail contracts, confirming what the Author had drawn attention to, and the view he (Mr. Price-Williams) held that what was wanted was a harder and tougher class of rail. Another important factor in the question was, undoubtedly, one which the late Mr. David Kirkaldy had always attached great importance to, namely, the amount of traffic tonnage the rails had been subjected to. He was aware that objections had been raised as to the difficulty in furnishing this information. He might state, however, that in the case of the Great Northern Railway, Mr. Johnson was kind enough to furnish it in the case of all the tests he (Mr. Price-Williams) had had carried out at Messrs. Kirkaldy's works; the possibility of slight errors in large quantities of that kind did not count at all, and he maintained that in spite of these objections the means were afforded of easily obtaining the requisite information from the accurate records which were kept of the train service. With regard to what the Author had said as to the inverted rail tests, the reversible rail was in very general use at one time, and a great deal of experience had been obtained of the objectionable feature the Author had laid so much stress upon, namely, the increased tendency of the rail to snap when the head, after having been subjected in compression to the enormous weight and speed of the traffic, was afterwards put into the reverse position in tension. This in fact was one of the numerous reasons which had led to the abolition of the reversible rail; in addition, there was the very objectionable and dangerous feature resulting from the galling of the under side of the rail in the chair to which the Author had drawn attention. He, however, concurred with him in thinking that the reversible rail tests afforded a very valuable aid in detecting any flaws in the material. One of the chief causes, undoubtedly, of this hammer

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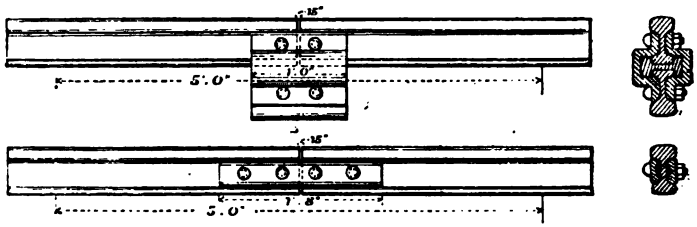
hardening was, as the Author had pointed out, due to the weakness of the rail at the joints; and the rapid deterioration of the head of the rail over the chairs nearest to the rail-joint was also, in his opinion, in a large measure due to the same cause. Another most objectionable feature in the roadway at the present time was the much closer spacing of the sleepers at the rail-joints, which was rendered necessary owing to the great weakness of the road there; the inequality in the spacing of the sleepers this occasions was, however, one of the chief causes of the hammer hardening effects alluded to in the Paper. In his opinion, next to improving as far as possible the quality of the material, the attention of railway engineers should be directed to the strengthening of the rail-joints so as to admit of the sleepers being equally spaced. As regards improving the quality of the material, the Author had referred, but only incidentally, to the question whether the strength and toughness of the rail might not be increased by the

Mr. Price-Williams.

Figs. 21a.



Scale ½ inch = 1 foot.

admixture of a small percentage of nickel; of the effect of that metal he could not speak. He might state, however, that a short time ago, with Professor Arnold's assistance, he had some steel made containing about 0·18 per cent. of sesquioxide of chromium, which the late Mr. Kirkaldy tested, and was so struck with the results that he consulted him on the subject, as, in addition to largely adding to its tensile strength its resistance to compression, upon which the Author laid so much stress, was increased by about 30 to 40 per cent. He was very pleased to learn from Mr. F. W. Webb that he was now using, with very satisfactory results, a mixture of chromium in his steel, and he was in hopes he might have been present that evening to give the results of his large experience on the subject under discussion. He (Mr. Price-Williams) had only to add that he exhibited at the meeting the results of his own efforts to strengthen the road, in the shape of a specimen of vertically and laterally fished rails, *Figs. 21a*, which

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Mr. Price-Williams.

had been tested recently by Messrs. Kirkaldy, side by side with specimens of Midland Railway fish-plates and rails kindly furnished him for the purpose by Mr. McDonald. The results of these tests showed that the vertically and laterally fished rails, as they might properly be considered, added very largely indeed to the strength of the road, as would be seen from a summary of the results of these comparative tests shown in the appended Table, from which it would be seen that the deflections and permanent sets of the Midland Railway Company's heavy 100-lb. rails, when fitted with his fish-plates, were only one-sixth of what the Midland Company's fish-plates experienced under precisely similar conditions of test, and that while the latter fish-plates deflected over 6 inches, and completely gave way (as the permanent set was the same) under a central load of 20 tons; the deflection of the vertical and lateral fish-plates only amounted to 0·82 inch, and with a permanent set of 0·38 inch, which with 3-foot bearings (instead of the 5 feet used in the tests) would be equivalent to a deflection of only 0·18 inch with no appreciable amount of set. The vertical fish-plates were only 1 foot in length and with only one fish-bolt on either side of the rail-joint, while the Midland fish-plates were of the ordinary type, 1·6 inch in length with two fish-plate bolts on either side of the rail-joint.

ABSTRACT FROM MESSRS. KIRKALDY'S TESTS, 7 OCTOBER, 1898.

Description.	Dimensions, Fish-Plates.	Weight per Yard.	Stress in Lbs.; Deflection and Set.							
			10,000	15,000.	20,000.	25,000.	30,000.	35,000.	40,000.	45,000.
		Lbs.								
Deflections, Midland Railway Company's 100-lb. rail, Price-Williams' fish-plate	Joint 12 ins. long	Rails 100·0	0·09	0·21	0·31	0·36	0·44	0·56	0·67	0·82
Sets	..	..	..	..	0·10	0·12	0·15	0·22	0·29	0·38
Deflections, Midland Railway Company's 100-lb. rail, Midland Company's fish-plate . . .	Joint 20 ins. long	Rails 100·0	0·08	0·20	0·88	1·47	2·42	3·40	3·79	6·57
Sets	..	..	..	..	0·64	1·20	2·09	3·05	4·35	6·09

Mr. Inglis.

Mr. J. C. INGLIS thought the railway contingent of the Institution would be exceedingly thankful to the Authors of the two Papers for presenting such a complete statement before them, and one which, he felt bold to say, would set the fashion largely in future rail tests. On p. 141 of his Paper, Mr. Kirkaldy stated that

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his father advocated, and had hoped to see adopted, standard sections for rails of definite weights, as well as standard specifications as to the quality of the steel. That was a subject to which he thought the Institution might give a little attention, and he was afraid American engineers had given the lead to Englishmen. In 1889 the American Society of Civil Engineers had, after an exhaustive inquiry into the most economical forms of rails, adopted standards, and they had designed them on the principles which they concluded were those advocated by the large majority of the Members of the Institution and experts in rails. They had designed rails from 100 lbs. downwards by 5-lb. intervals to 40 lbs. He had visited Messrs. Carnegie's works in the autumn of 1898, and he was informed that the adoption of those standard sections of rails was largely on the increase. He need not point out that the adoption of a standard rail meant the abolition, as one manufacturer expressed it, of his 10-acre plot for spare rolls, thus enabling the manufacturer to change, with greater freedom, the old rolls for the new, and so deriving a higher class of output on the whole. As to the quality of the rails, he had occasion, not very long ago, to make inquiry in America about a large lot of rails, and he sent over the English specification. His experience was not quite in accordance with that of the last speaker, because he obtained the answer that they would be very glad to supply the rails on the following specification :— Mr Inglis.

THE CARNEGIE STEEL COMPANY'S STANDARD SPECIFICATIONS FOR STEEL RAILS, JANUARY 1, 1897.

Chemical Composition.

—	60 Lbs. and under (29·76 Kilograms per Metre).	Over 60 Lbs. and up to 80 Lbs. (29·76 Kilograms to 39·68 Kilograms per Metre).	Over 80 Lbs. and up to 100 Lbs. (39·68 Kilograms to 49·61 Kilograms per Metre).
	Per cent.	Per cent.	Per cent.
Carbon . . .	0·35 to 0·45	0·40 to 0·50	0·45 to 0·55
Phosphorus . .	Not to exceed 0·10	Not to exceed 0·10	Not to exceed 0·10
Manganese . .	0·60 to 0·80	0·70 to 0·90	0·80 to 1·00
Sulphur . . .	Not to exceed 0·05	Not to exceed 0·05	Not to exceed 0·05

Weight and Section.—The weight of the rail shall be maintained as near as possible to that specified in contract. A variation of 1 per cent. for individual rails and ½ per cent. for an entire order will be allowed. Rails shall be accepted and settled for according to actual weights. The section of the rail rolled shall conform as accurately as possible to the templet furnished by the Railroad Company, consistent with the above clause relative to specified weight. An allowance in height of $\frac{1}{64}$ inch (0·40 millimetre) under and $\frac{1}{32}$ inch over will be permitted. A perfect fit of the splice bars, however, shall be maintained at all times.

Length.—The standard length of rails shall be 30 feet (9·144 metres). Shorter rails to the extent of 10 per cent. of the entire order will be accepted

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Mr. Inglis. in lengths of 28 feet (8·534 metres), 26 feet (7·925 metres) and 24 feet (7·315 metres). No rail shall vary more than ¼ inch (6·35 millimetres), either under or above, from the prescribed length.

Branding.—The name of the maker and the month and year of manufacture shall be rolled in raised letters on the side of the web, and the number of the heat shall be stamped on each rail.

Drilling.—Circular holes shall be drilled in accordance with specifications of purchaser. They must be accurate to drawing and dimensions furnished in every respect, and free from burrs.

Finishing.—Rails to be straightened while cold, and prior to shipment must have the burr occasioned by saw-cutting removed, and the ends made clean. They are to be free from mechanical defects and flaws of all kinds.

Inspection.—The inspector representing the purchaser shall have free access to the works of the manufacturer at all times while his contract is being executed, and shall have all reasonable facilities afforded to satisfy him that the rails are being made in accordance with specifications.

The manufacturer shall furnish the inspector daily with carbon determinations of each heat, and a complete chemical analysis every 24 hours, representing the average of the other elements contained in the steel.

No. 2 Rails.—Rails which possess any physical defects or for any other cause are not suitable for first quality shall be considered No. 2 rails, to be applied against contract to an amount not exceeding 5 per cent. and at a reduction in price of 5 per cent. from that agreed upon for first-quality rails.

The specification was very short, as all American specifications were, and very precise; and it simply stated the chemical composition. There the proportion of carbon for rails of 80 lbs. to 100 lbs. was between 0·45 per cent. and 0·55 per cent. Specifications in Great Britain gave the margin of carbon as 0·45 per cent. to 0·50 per cent.; so that the practice in the United States regarding carbon was not very different from the English. The only noticeable point in the American as compared with the British specification was in the amount of manganese; that was greater in America than in England. He had never heard of 0·7 per cent. of carbon in America; and his inquiry had reference to negotiations on a large scale. As to the hammer-hardening of rails, which he regarded as the crux of the whole subject, that was, unfortunately, not a new story. Among his curiosities he had found a broken rail which supported exactly the statements of the Author, and illustrated exactly the process which had been described, and shown so beautifully in the photographs of rails which had failed. It was a broken rail which had fractured from the precise cause mentioned by the Author. He desired to show that these minute cross cracks were not such an extraordinarily rare disease; it was one that had been known of, but which, so far as he knew, had only been noticed on rails which were considerably fatigued. That statement embodied an experience which he had had so far as breakages and failures on the Great Western Railway were concerned. It was a matter which his Company looked upon with a certain amount of anxiety, but it did not produce any consternation. They had other samples

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where the fractures visibly ended at a very shallow depth, and to know the reason of that he would like to hear Sir William Roberts-Austen's opinion as to whether these minute cracks might not be due to the difference in the expansion of the materials of the steel after it had been so altered in constitution by the hammering referred to in the Paper. Members knew that that hammering process made steel so hard that it could not be impressed by a tool; and the photographs illustrating Sir William Roberts-Austen's Paper—together with his subsequent remarks and explanations, which he thought fully as interesting as the Paper—clearly showed a total alteration in structure of the rail and the steel. He would like Sir William's opinion as to whether that alteration in structure which was known as hammer-hardening must alter the rate of expansion of the metal. The surface-metal being thus altered while the internal metal was not might be the reason for those cracks occurring. He showed another specimen of a similar crack combined with a locomotive-wheel mark, doubtless starting with the rail either dry, or rubbing the rail and indenting it. That fracture was accompanied by a similar small transverse crack close to the main fracture, and no doubt was associated with it. Whether it was there before this exceptional wear took place on the rail, or whether it was caused by it, he could not say; he only pointed it out as an instance to be considered—that there was the same class of fracture associated with rough usage, such as it received when an engine attempted to start, and the wheel revolved without the engine moving bodily. He desired also to refer to the very valuable observation which the Author seemed to make clear, namely, that a soft rail was fully as liable to this process of deterioration as a hard one, which he thoroughly believed. The number of experiments the Author had made was comparatively small with regard to the evidence in the Paper, but he thought it was a fair inference from the Paper, at p. 155, where the Author stated he found that a pressure of 33·5 tons per square inch showed that a soft rail did not avoid this excessive development of the minute fracture he was describing. That entirely agreed with his own experience. With Mr. Ross, engineers had been seeking a harder and tougher steel. That point pressed on railway engineers chiefly in the matter of fittings, and he had found it necessary to take steps in that direction. He had made extensive enquiries, and had a large quantity of open-hearth steel rails rolled. The Great Western Railway Company many years ago had purchased from a Welsh company a number of ingots of the Siemens-Martin process and rolled rails from them, and they had had no rails which wore so well. This experience gave the lead,

Mr. Inglis.

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Mr. Inglis. and he had a number of rails rolled with Siemens-Martin steel, and precisely to the cross-section or to the standard of the rail which they now used. He had these tested physically and chemically, and also side by side with a number of similar tests on the same rail by the Bessemer process. There was no doubt that by the Siemens-Martin process a harder and tougher and more reliable rail could be obtained. But, unfortunately, the cost was £2 per ton more in England, and that prohibited, except for the matter of fittings, the Siemens-Martin rail for ordinary use. The result of investigations with the open-hearth steel was, on the average, 49·16 tons stress per square inch, with an elongation between points 2 inches apart—which was almost a standard distance—of 13·18 per cent., whereas the similar lot of rails by the Bessemer process gave 43 tons to the square inch, and an elongation of 20 per cent., showing that the open-hearth rails had a less elongation, by the difference between 13 per cent. and 20 per cent. But unless this was an average, it would be of no value; the result, however, were so uniform that they showed the rate of elongation could be depended upon. The experience of his Company had been in accordance with those results, and they were now using them for the parts of the fittings which were more stressed than others. He mentioned that simply to show the direction in which railway companies would be driven, at any rate, beginning with fittings. Very likely manufacturers could also make cheaper rails. With regard to the depth of the rail, he would rather have $\frac{1}{8}$ inch greater width in the top than $\frac{1}{2}$ inch greater depth. As to his reasons for that opinion, he had in his mind a somewhat large case of relaying of rails where the subsoil was soft. It was ballasted thoroughly with a new road, twelve sleepers being set to a 32-foot rail. That road could not be made to settle down into what they regarded as a first-class running road; and after a good deal of investigation he decided to try thirteen sleepers to 32 feet. The thirteenth sleeper had the effect of getting over the difficulty; and he did not hesitate to say that in all cases of soft formation, and in certain cases of curves where they had used thirteen sleepers where previously twelve had been laid the best results had followed. They had been able to reduce the labour, and it only showed that the weakest part in the present permanent way was in the area of sleeper bearing on the formation; and it appeared to him that in a 95-lb. or 100-lb. rail a girder was already obtained sufficiently strong to do what was required. But care was necessary to build on good foundations, and it seemed that the spreading of the area on that was very important. With regard to the width, he had had occasion to take diagrams, and he

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found in the best class of road that the lateral oscillation was five or six times that which occurred vertically. That only showed that the movement and knocking on the side of the rail was considerably greater than that operating on the top on a good road. In some roads the blows were exceedingly violent, and he thought the Author might add to his *a b c d*, on p. 158 of the Paper, a fifth heading—*e*, taking into account the side oscillations due to horizontal knocks. This subject had been brought under his attention a good deal, and perhaps he had been in an exceptional position to estimate it, because his Company had to deal with longitudinal road. It was known that the individual parts on that type of road were more rigid longitudinally than the individual parts of a cross-sleeper road, although the weakness in a longitudinal road was the want of sufficient tie. As to rail joints, he would only state his opinion that with the increased weight of rail the importance of the joint diminished. It did not vanish, but it was not so acute as it was in the earlier stages when the rails were lighter. He was exceedingly glad to hear Sir Lowthian Bell state his general conclusions with which his own small experience, and that of those who advised him, entirely agreed, namely, that there was a capriciousness about the behaviour of steel—at any rate about its failures—which was not disheartening, but which, with the prospect of further research, such as that shown in the two Papers, particularly Sir William Roberts-Austen's, gave hope that out of the chaos order would yet prevail. He could not help thinking that by a further Paper, showing the effects of alloys individually, or showing that the finer the grain of steel the more reliable it was, a good deal would be done towards a simple inspection sufficing to judge of the quality. He noticed that the Author spoke disparagingly of the drop test. He admired the Author's accurate scientific observations, but having personally to buy large quantities of rails and test them, he would not like to forego the privilege of the drop test, and he thought that if the Author asked any locomotive engineers to forego that test in the matter of their tires, for instance, he would have to go a long way before he got one to say "Yes." The rail failed from a series of blows, and he could quite understand an incipient flaw standing a certain amount of static pressure, but with a sudden application or jerk it would be revealed. Mr. Inglis.

Mr. HARRY FOOTNER felt, in common with many other engineers, that the profession was much indebted to Mr. David Kirkaldy for what he had done some years ago in relieving them from that delusive security of famous brands by a rational system of testing by which the quality of steel or iron was proved independently of Mr. Footner.

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Mr. Footner. where it came from. He was glad that his son was applying himself to the investigation of the condition of steel rails, in which it was stated that induced cracks were developed by the action of the wheels, resulting ultimately in fracture. He was able, however, to testify that in practice an extremely small number of rails broke in the road, that he did not remember any mishap on the London and North-Western Railway which was due to a broken rail. During the last 12 years he had recorded certain particulars of every case that had occurred. From every rail broken two bars had been cut and tested transversely. In some cases there had been tensile tests of the material as well. At least 40 per cent. of the fractures were not the result of induced cracks, because in these the flaws were found only in the web and in the foot of the rail, the head appearing to be quite sound. The total number broken was 388, and assuming the average life of a rail to be 20 years, and there were 7,400 miles of single rail in the running lines of the London and North-Western Railway, that would give an average of 1 rail in 2,000 breaking in the road. In trying to ascertain the primary cause of the breakages he had noted and classified the rails according to their position and conditions of service in the track. As regards the seasons they broke as follows:—29 per cent. in the spring, 16 per cent. in summer, 22 per cent. in autumn, and 33 per cent. in winter. As regards their position in curves and tangents, 27 per cent. broke in curves from 5 to 60 chains radius, 24 per cent. in curves of radii exceeding 60 chains and 49 per cent. in straight lines. Of those broken in curves nearly two-thirds were in the lower rail. As regards the position of the fractures—

11 per cent. subjected to brake action 26 „ „ not subjected to brake action	broke between the fish-plates within 10 inches of the end of the rail.
36 per cent. subjected to brake action 27 „ „ not subjected to brake action	broke elsewhere at various parts of the rail.

Of the fractures between the fish-plates 85 per cent. were at the end at which the wheels came on them, and 15 per cent. at the end at which the wheels left them. Of the fractures not between the fish-plates 30 per cent. occurred at a chair, and 70 per cent. between the chairs. As regards the weights at which 84-lb. bull-headed rails broke—

10	per cent.	broke	between	84 lbs.	and	80 lbs.
31	„	„		80 „		75 „
28	„	„		75 „		70 „
16	„	„		70 „		65 „
11	„	„		65 „		60 „
4	„	below		60 lbs.		

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As regards the weights of traffic carried by the rails before breaking— Mr. Footner.

3 per cent. broke after carrying between				¼	million and	2½	million tons.	
35	„	„	„	2½	„	25	„	„
45	„	„	„	25	„	50	„	„
17	„	„	„	50	„	100	„	„

The life of the broken rails in the line was—

3 per cent. between		0	years and	5	years.	
23	„	„	5	„	10	„
36	„	„	10	„	15	„
24	„	„	15	„	20	„
4	„	over	20 years.			
10	„	age unknown.				

From the foregoing particulars it was seen that neither the age nor the weight of the rail, nor the amount of traffic, nor the influence of the seasons, nor the position in curves and tangents, nor the action of brakes or trains starting, took any such leading part as to justify the assumption that any one of them determined the fractures. That more broke at the joint than elsewhere without taking into account manufacturing defects at the ends, it might be anticipated that many would break between the fish-plates owing to the tensile stress in the web caused by the fish-plate bolts tending to force the head and foot of the rail apart assisted by the leverage of the fish-plates and concussions of the wheel passing from one rail to the next. The test bars cut from broken rails of the bull-head section supported at the ends and broken by a central load gave the most diverse results; but generally speaking old rails often failed with greatly reduced loads and deflection when the head was placed in tension, and this weakness was confirmed by the direct tensile tests of the material taken from the head and foot of the rail respectively. Similar tests from new rails of this section pointed to the existence occasionally of some difference in this respect, but in a far less degree, and he would like to know whether the unequal rate of cooling of an unsymmetrical section would sufficiently account for it. He was prepared to believe that the concussions a rail was subjected to, when under rapid alternations of stress by the blows of flattened wheel tires, had a damaging effect upon the running surface and the parts of the head adjacent, and these might determine the moment of fracture of an imperfect rail; but he was of opinion that the primary causes of rail fracture did not have their origin in the treatment of the rail in the track, and that engineers must chiefly look to an alteration in the ores used in making the steel,

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Mr. Footner. and to an improved manipulation in every stage of manufacture for a greater immunity from these breakages, the practical question was whether an improvement could be obtained without adding too much to the cost of the rail. Mr. Walter Katte, the chief engineer of the New York Central Railway, had used rails with 0·5 to 0·6 per cent. of carbon with 1·1 and 1·3 per cent. of manganese for an 80-lb. rail, and had informed him that with phosphorus not exceeding 0·06 per cent., and sulphur 0·069 per cent., great toughness and elasticity had been obtained, with results satisfactory in the highest degree, for some years past. He hoped Mr. Kirkaldy would have the opportunity of continuing his tests, which were valuable from their extreme accuracy.

Mr. Deacon Mr. G. F. DEACON remarked that, as compared with railway rails, the question of tramway rails was less important at the present time; but mechanical traction was destined, he thought, to have the effect of reducing the discrepancy. Certain experience of the behaviour of tramway rails had an important bearing upon railway practice. Twenty-two years ago he had occasion to relay the Liverpool tramways, which were among the first urban tramways laid in England. After a few years of the working of the American lines, which had previously been laid down, the Corporation obtained powers to take them over and to reconstruct the permanent ways. Naturally he gave a good deal of attention to the subject before coming to a decision, and when he did come to a decision, it was to lay the lines at the same time as the renewal of the pavements, and to do so upon a concrete foundation; but to place between the concrete foundation and the rails an elastic cushion of timber, that cushion not to be loosely laid like an ordinary sleeper but to be jammed, as it were, between the rails and the concrete foundation by fastenings, which passed through the cushion and concrete and held the rails down to the under side of the concrete foundation. Except as consulting engineer, he only acted for that department for some 3 years after that, and he had therefore had nothing to do with the constructive work that immediately followed. But what he did at the time was to relay the whole of the Inner Circle, as it was called. That Inner Circle was completed in the year 1877—22 years ago. From the Inner Circle there were radial lines, and the whole of the traffic of those radial lines passed nearly all the way round the Inner Circle; some of it passed the whole distance round, and all of it most of the distance round, so that the traffic on the Inner Circle was evidently very much greater than that on any of the other lines. Two years ago he was called in again to look into

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the matter and explain the reason why the tramways of the Inner Circle had never been taken up, while all the others subsequently laid had been taken up and renewed more than once. He would refer only to two streets, for the reason that the traffic was not exactly the same on the whole of the Inner Circle, nor was it exactly the same on all the branch lines. The two streets were Lord Street—of the Inner Circle non-rigid system—and Scotland Road of the branch lines, rigid system. The general principle of the rigid system portion was the same as that of the non-rigid system, except that a cast-iron sleeper was substituted for the timber cushion. Measured in terms of weight of traffic against quantity of steel worn away, the wear in the case of the Lord Street, non-rigid rails, was only 35 per cent. of that of the Scotland Road rigid rails. That was the leading fact, and it had been noticed by others who were not engineers. He confessed he was so surprised at that result—not at the fact of a result of the kind, but at the intensity of it—that he sought for an explanation beyond the mere change in the elastic condition of the rails and sleepers. He first investigated the difference of the ordinary vehicular traffic, which was not included in the weight of tramway traffic by which the above percentage had been obtained. It was found that there was just about four times the vehicular traffic on the Inner Circle non-rigid, as on the Scotland Road rigid lines, during the lives of the rails respectively. He then investigated the frequency of the use of the brake, and in Lord Street (non-rigid) the brake was used three times as frequently during the lives of the rails respectively as in Scotland Road (rigid). The last speaker had, 13 years ago, pointed out, he believed for the first time, that corrosion was affected very largely by wear.[1] Rust on the surface of a rail, like that on the interior of water-pipes and other apparatus, constituted a more or less protective coating against further rust; but if traffic passed frequently over a rusting surface, the rust was almost continuously worn off, and the coating was never allowed to become really protective. There were two possible causes of difference of deterioration by rusting in the two places; one was the quantity of manure, and the other was the impurity of the atmosphere. But the quantity of manure deposited on the rails of the Inner Circle (non-rigid) was greatly in excess of that deposited on those of Scotland Road (rigid). In point of atmospheric effect he came to the conclusion that there could be no appreciable difference. Having thus settled to his own satisfaction

Mr. Deacon.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 438.

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Mr. Deacon. that all the external causes of wear were in favour of the longevity of the rigid system which by comparison wore so badly, he investigated the mechanical properties of the rail itself in the two cases, and then the chemical properties. In the first place, with regard to the mechanical properties: a number of pieces of different rails were sent to Professor Unwin, and he tested them for hardness and for elasticity and other mechanical properties.

The following Table summarized the results:—

—	Hardness Number.	Elastic Limit.	Tenacity.	Elongation in 8 inches.
		Tons per Sq. In.	Tons per Sq. In.	Per cent.
Inner Circle, Lord Street (non-rigid) . .	204·5	22·7	37·9	19·5
Branch line, Scotland Road (rigid) . .	218·3	24·3	43·6	14·2

Even the hardness, therefore, was a little in favour of the rigid lines, but the difference was small. The chemical tests also showed that there was practically no difference between the steel in the rigid and the non-rigid constructions. The results were as follows:—

—	Lord Street (non-rigid).	Branch Line, Scotland Road (rigid).
	Per cent.	Per cent.
Carbon	0·442	0·428
Silicon	0·056	0·064
Phosphorus	0·054	0·040
Manganese	0·672	0·600
Sulphur	Under 0·080	Under 0·080
Copper	Bare trace	Bare trace

So that all the conditions that it had occurred to him to investigate for the purpose of showing that comparative elasticity was not the only explanation of the difference, supported the view that it was the only explanation. They either gave practically identical results, or were in favour of the longevity of the rails which had been laid on the comparatively rigid system, leaving the conclusion that the comparatively rigid system gave an effi-

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ciency measured in terms of intensity of load and of wear of the rail less than 35 per cent. of that of the non-rigid system. This result was certainly startling, but after taking great pains to discover any other cause than the difference in point of rigidity of the two cases, he had been forced to the conclusion that the great durability of the Inner Circle, as compared with that of the branch lines was solely due to its less rigid though firm construction. Mr. Deacon.

Sir FREDERICK BRAMWELL, Bart., wished to state two difficulties that he felt. In the year 1853 he was in the United States and saw one piece of railway in Virginia of the old construction—flat bar iron laid upon a continuous bearing, the bar held down by spikes, and having a bird-mouth joint at the ends. He saw the carriages had bars fixed to them for the purpose of preventing the ends of the rails from being forced up through the seats and so injuring the passengers. This precaution was needed because the result of rolling of the wheels over these bars of iron was—instead of curving them downwards, as he should have thought would have happened—to cause them to curve upwards, and thus the ends of the bars rose; with the result that if the wheel, instead of going over the curved up end and setting it down, went under it and lifted it, an accident took place. That was effect No. 1 of rolling the surface. Then came No. 2. When he was an apprentice it was customary to make metallic pistons by turning the rings to the size of the cylinder, then cutting them open in one place, and then hammering the inside of the iron with a hand hammer, thereby expanding the ring outwards, as he thought it ought to expand, the effect being that the iron inside was elongated and the thing expanded. In the case of the rail the iron appeared to be shortened and the thing curled upwards. He could not comprehend those two things. If he might be allowed to refer to a somewhat analogous case of very different material for a different purpose, he would say that when a cook wished to decorate a knuckle of ham with one of those curly paper things which were often seen, those papers were produced by drawing them over the blade of a knife. Any member could try the experiment, and it was known as a result that the paper would curl towards the blade over which it was drawn like the American rail curling towards the wheel which went over it. He did not know why; he merely stated those facts. He could quite understand that, if for some reason or another, the rail wished to curl upwards as it did in old days when it was a flat bar, and it was made in these days into a girder of 6 inches deep, so that it Sir Frederick Bramwell.

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Sir Frederick Bramwell.

could not curl upwards, the result must be to produce the minute transverse cracks. But he did not know why it wanted to curl upwards.

Professor Arnold.

Professor J. O. ARNOLD had read Mr. Kirkaldy's Paper with much interest and admiration, and that of Sir William Roberts-Austen with a little surprise. In December, 1895, he had the honour of reading before the Institution a Paper,[1] in which was announced for the first time the determination of the saturation-point at 0·9 per cent. of carbon, and which traced up very clearly the relation of ferrite and pearlite; and not only that, but during the discussion he pointed out the lowering of the saturation-point by manganese; and at the end of the meeting, Mr. Andrews, who had applied to steel rails the principles privately enunciated to him some time before showed on the screen a dozen sections of steel rails resembling those which had been shown. He thought therefore that it was hardly accurate to say that the subject had not been brought before the notice of the Institution. In making micrographic analyses of a steel rail it was necessary to take the history of the rail into consideration from the time it left the Bessemer converter. If a rail was cast in a 16-inch ingot and the metal was very hot, there was certain to be more or less liquation; that was, the top of the ingot would be higher in carbon, in sulphur, and in phosphorus, than the bottom, and the centre would tend to be higher in those elements than the outside. So that in investigating a steel rail to make micro-sections of it, it was necessary to explore the rail very thoroughly in the manner which he (Mr. Ross) had done chemically, not only along the length but through the whole section at each end, in order to get its chemical analyses and its micrographic analyses in different parts. He might mention the case of a steel tire he had examined some time ago in which two adjacent test-pieces had been tested. One gave an elongation of 9 per cent., and the other of 31 per cent., pieces lying adjacent to each other in the same tire. On investigation it was found that, even in that small tire, a large difference in composition and in microscopic structure existed. He thought the piece which gave the good elongation contained 0·03 per cent. of sulphur, while the sulphur in the unductile piece was about 0·12, and very similar results were shown in Mr. Ross's analytical diagrams of his rail. The sections shown by Sir William Roberts-Austen were rather different from those he had examined—a fact possibly due to

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 127.

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the difference in the method of preparation. He fancied that the magnification selected by Sir William Roberts-Austen, 140 diameters, was a little unfortunate. It was too large to enable the section to give a good wide view of the distribution of the iron and steel or otherwise of the ferrite and pearlite, whilst the magnification was not sufficiently large to give a good idea of the junctions between the ferrite and the pearlite. He had looked at the sections very closely, and perhaps Sir William Roberts-Austen would explain, why the whole of the ferrite in those sections seemed to be amorphous. All sections that he had made of steel rails presented crystallization in the ferrite itself, and the joints of such ferrite of course formed an important part of the strength of the material. He also noticed another peculiar feature of those sections, namely, the entire absence of sulphide of iron, although it was stated that the sulphur ran from 0·04 to 0·09. In his examinations of steel rails containing sulphur as high as 0·09, at any rate by his method of preparation, he could trace the sulphur distinctly dotted throughout the mass quite as well as the pearlite and ferrite; and as sulphur was likely to be an element of the greatest importance in the investigations about to be made on steel rails, it seemed to him a method of preparation should be used which showed it clearly. He was quite unable to detect its presence in any of the micrographs which had been shown. With reference to Mr. Kirkaldy's Paper he agreed with most of his conclusions; the Author had shown very clearly a remarkable effect. From the point of view of the metallurgist there remained to find out the cause, and the evidence on every hand was so conflicting that there was evidently a very difficult and long research to be made before metallurgists could explain the remarkable vagaries of steel rails. Increased hardness, he thought, was a little apt to frighten some railway engineers; but he should explain, knowing Mr. Kirkaldy's views, that that hardness was not necessarily carbon hardness. For instance, he did not think Mr. Kirkaldy would advocate an advance of the carbon to 0·6 or 0·7 per cent. He really meant to maintain a sufficient quantity of ferrite (and it should be remembered that the ferrite would disappear at 0·7, with 1 per cent. of manganese), to retain in the micro-structure a sufficient quantity of ferrite to give ductility. But what he really suggested was to harden the matrix of ferrite with some element like nickel, manganese or chromium, as suggested by Mr. Price-Williams. He thought it very likely that there was a good deal to be said for that view. He agreed with the speaker who asked Mr. Kirkaldy not to speak

Professor Arnold.

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Professor Arnold. quite so hardly of the drop-test. He did not think if a rail was balanced carefully between centres, and a definite amount in foot-lbs. was dropped upon it, that it could be called a crude test. What it did was certainly to give the steel a test from a vibratory point of view, a vibration along the steel which no other class of testing could do. The hammer hardness which had been spoken of in the rails, it should be remembered, was only skin deep; it was only really a skin on the surface of the rail. All railway engineers were aware that there was a reciprocal skin upon the face of a tire. When a tire was turned up, it was just as hard as the surface of the rail. In fact it was very difficult to find turning-tools which would face the skin of the tire, it was so intensely hard. He thought the hardness, as tested mineralogically, was somewhere about 7½ on the mineral scale, which was exceedingly hard. Mr. Kirkaldy had mentioned induced flaws; he thought he had shown that in some cases these flaws were not produced, while in others they were produced and apparently in the same composition. He should rather like to substitute the term "potential flaws," because if the analysis and structure of the steel were correct, he did not think that those flaws should develop. Anyhow, it struck him that Mr. Kirkaldy's results had been made so carefully, and contained matters of so much interest, that some time ago when he met him he volunteered to complete his remarkable mechanical observations with a careful set of chemical and micrographic results. When these were finished, he had no doubt that the results would be laid before the Institution, and then the members would have a complete series of results, mechanical, chemical and micrographical, on rails of known history.

Mr. Robertson. Mr. F. E. ROBERTSON noticed that, in the first Paper, the Author used the term stress and load as synonymous. He could hardly call the load which deflected a beam the stress in the beam; and that cast a doubt throughout the Paper as to whether the results meant the stress on the ultimate fibres of the rail, or the load on the rail which developed those stresses. The Tables would have been more easily read if they had been arranged in the order of hardness of the rail or endurance. It seemed *a priori* not unreasonable to suppose that a harder steel would resist better the local action of the wheels than a softer steel, and so escape the incipient flaws which ultimately led to fracture. But although he held that opinion, it was one for which, so far as he knew, there was no absolute proof. American practice tended in the direction of harder rails. A previous speaker had doubted whether

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Americans used such hard rails as 0·7 per cent. of carbon. The following Table showed the specification of the New York Central Railway by the well-known railway chemist, Dudley, and W. Katté, the Chief Engineer:— Mr. Robertson.

Weight of Rail, Lbs. per Yard.	65	70	75	80	100
Carbon . . per cent.	0·45–0·55	0·47–0·57	0·50–0·60	0·55–0·65	0·65–0·70
Manganese . „	1·05–1·25		1·10–1·30		1·2–1·4
Silicon	From 0·15 per cent. to 0·20 per cent.				
Sulphur	0·069 per cent. maximum.				
Phosphorus	0·06 „ maximum.				

He inclined to the view of American engineers in thinking that possibly harder rails might be used, but the analogy of wire-drawing seemed to him to be rather against that. Was it not the fact that a harder billet would require annealing after passing through the dies more than a soft one, and would not the action of the dies be very much the same principle as the hammering of the wheels on a rail? He could not find also that the Author's facts quite supported his conclusions. For instance, in the first series there was a rail of 44½-ton steel which broke in the road, while its neighbours—which only averaged 36 tons tensile strength, and some were as low as 34—did not break. If that first rail was the rail alluded to in the first column of Table I, p. 184, it was possible that a high phosphorus and other impurities might account for its being brittle. Then in the second series a 36-ton steel was singled out for special commendation, but a 36-ton rail was not a very hard one; it was a fair medium rail. In the third series the 60-ton steel behaved admirably, but then there were two other hard rails which broke in the road. The analysis of those rails might throw some light on the difference in the behaviour of them. In the remaining series, the tensile tests given were too few and too uniform to point to any very definite conclusion. But he had some tests of rails which would help to give some evidence on the subject. There were some rails that were 30 years in the main line of the Taff Vale Railway, which had a very heavy traffic. Those rails were taken up because heavier rails were required. They had worn so admirably that it was thought desirable to make some investigation into their qualities. Therefore six pieces were taken and tensile tests and

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Mr. Robertson. analyses were made from different parts of the rails. They were very uniform, and the average figures, which he would mention, would represent fairly any one of the tests. The rails were 76-lb. rails, and were laid in 1866 and taken up in 1896, weighing 71 lbs. a yard. The tensile strength gave 35½ tons; the elongation was 20 per cent., and the contraction of area 40 per cent. on 10-inch test pieces. The average analysis was:—carbon, 0·378 per cent.; silicon, 0·044 per cent.; sulphur, 0·047 per cent.; phosphorus, 0·056 per cent.; arsenic, 0·031 per cent.; manganese, 0·34 per cent. The microscopic examination of the heads showed no sign of flaws. One could not reasonably expect better service from rails than those gave, but they could scarcely be called hard rails—they were good medium rails. He noticed also the rail shown by Sir William Roberts-Austen, in Fig. 6, and spoken of as a very excellent rail, could not be called a very hard rail, for with full amount of phosphorus its tensile strength could scarcely have been above 38 tons. Now all the good rails fell within the limits of the specification his firm were in the habit of using, which was carbon 0·3 to 0·45 per cent., and other impurities not to exceed 0·06 per cent. for any one of them. If that specification gave safe rails, and the rails wore as well as the figures seemed to indicate, was it worth while taking chance and getting harder rails for possibly a better wear? Would the harder rails wear any better? He had two analyses of rails that came in that day, and they were very much the same as the Taff Vale rails. One came from the North and one from Wales. With regard to the rail from Wales, the analysis was, carbon 0·367 per cent., silicon 0·020 per cent., sulphur 0·050 per cent., phosphorus 0·035 per cent., manganese 0·565 per cent., arsenic 0·028 per cent. The rail from the North had, carbon 0·370 per cent., silicon 0·034 per cent., sulphur 0·057 per cent., phosphorus 0·031 per cent., manganese 0·456 per cent., arsenic 0·009 per cent. Those were very fair average rails, and such rails seemed to wear very well. After 30 years' experience of using rails in India, where the traffic, of course, was not so intense as it was in England, it seemed to him that the most practical point to avoid breakages was to leave plenty of crop end. He thought that more than half, probably 75 per cent., of the broken rails that had come under his observation had been due to mechanical flaws in the rolling. In any case, in India, at least, broken rails did not cut a large figure, for during the years he was chief engineer of the East Indian Railway the percentage of broken rails was 1 in 495,000 per annum, the average age of the rails that broke being 11 years. It was to be hoped that the

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Royal Commission now sitting would afford some useful information on that very complex subject, because when even the tensile strength and the chemistry were known, all was not known about the rails. It was certain that the treatment during rolling profoundly modified the product, and it might be possible that even the distribution of the work had some effect—that a certain number of trains might not have the same effect if they passed in one day as if they took ten days to pass; there might be a higher ratio of wear if the traffic was more intense. Then, again, to collect data from worn rails was not so very simple. Just lately he had a case before him where a road in India, laid with narrow round-top rails, was being re-laid with flat-top wide rails. The tires grooved by the narrow rails were running, of course, on the edges of the new ones, and the wear was so intense that flakes of steel were worn off the new rails just like wood shavings, some nearly an inch long. Certainly rails which had been subjected to that treatment could not be expected to give as good results as rails which had normal treatment from a tire that fitted them. Sir William Roberts-Austen's Paper was very interesting, and it was to be hoped that he would continue the study, and place in the hands of engineers a more powerful weapon for the search for that much desired but difficult matter to attain—to know what was the best rail. Mr. Robertson.

Mr. W. H. Preece, C.B., President, said that, before he asked Mr. Andrews to continue the discussion, he thought it right the members should know that, as an exception in this case, slides would be allowed to be shown to illustrate the remarks that were made. As a rule, in discussions, the Institution did not permit slides to be used, because they were ephemeral, and attention during discussion could not be called to them and to debatable points so illustrated; but in this particular instance, owing to the fact that the work to be shown was so delicate, and of such a character as to render its embodiment in ordinary diagrams impossible, the first three speakers would be permitted to illustrate their remarks with lantern-slides. Mr. Preece.

Mr. Thomas Andrews observed that one of the great points in connection with rails in the future was whether they were to be low-carbon and low-manganese rails, medium-carbon and medium-manganese rails, or high-carbon and high-manganese rails. As consulting metallurgical expert to the Great Northern and other chief British railway companies, opportunities had been afforded him of carefully investigating that most important question over a number of years, experimenting upon typical samples from many Mr. Andrews.

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Mr. Andrews. thousands of tons of rails, not purposely selected, and in connection with no theory, and he desired to show several instances of the advantage of the chemical analysis of steel rails and of the microscopic investigation thereof. The first slide exhibited a type of the high-carbon rail containing also micro-flaws which could be observed scattered about. The high-carbon rail was given to segregation of the carbon contents, and segregated areas were scattered throughout the mass of the rail in which considerable liability to fracture was present. The white portions were areas of ferrite, and the grey portions consisted of carbide of iron. There was an unevenness of texture in high-carbon rails which was detrimental to the life of the rail. The next slide showed the wearing face of a rail of the medium-carbon and medium-manganese type, a low-carbon and a low-manganese rail being one which in carbon contents was below 0·35 per cent. and the manganese contents below 0·7 per cent. The next grade of rails he should class in the following manner:—Medium carbon and medium manganese, speaking roughly, were rails ranging from 0·35 per cent. to 0·42 per cent. of carbon and the manganese from 0·7 per cent. to 0·85 per cent.; beyond 0·42 per cent. of carbon, and beyond 0·85 per cent. of manganese, he preferred to class them as a high-carbon and high-manganese series of rails. Most of the rails would come under one or other of those subdivisions. The one shown on the slide was a low-carbon and low-manganese rail, and it had worn 24 years in the main-line service on the Great Central, or old Manchester, Sheffield and Lincolnshire Railway. There was no deterioration detected beyond the grinding down of the face of the rail. There were no transverse cracks. The wear would not be more than about 0·3 lbs. per yard per annum over the long life of 24 years. The rail was simply taken out because of its actual grinding down on the face; no defect was perceived in it. The next slide exhibited the micro-structure of the rail which he had just shown, with a magnification of 300 diameters. It would be seen that there was an adjustable sort of arrangement between the carbide areas and the white ferrite, an even interlocking structure, so that there were no carbide areas running into each other as in the high-carbon case. It was an interlocking structure as between the ferrite and the areas of pearlite, and that was the one which was most likely to endure the wear and tear of railway work. The percentage of carbon in the rail was about 0·25 and the manganese 0·43. The next slide showed a rail from the Great Northern Railway which had worn for 23 years, the carbon

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contents of the rail being 0·34 per cent. and the manganese 0·478 per cent. It was an old rail, and had worn exceedingly well, with no indication of deterioration perceptible either microscopically or on the rail face beyond the few slight longitudinal flaws which could be seen running the length of the rail. Another slide represented the micro-structure of the preceding rail. The same interlocking structure could be seen as between the ferrite and carbide areas. When the carbon increased, those areas tended to run into each other and formed lines of weakness across the face of the rail, leading, under the influence of stress, to fine transverse cracks. The next slide showed the face of a rail after 18 years' wear, a medium-carbon and medium-manganese rail containing carbon 0·36, manganese 0·77 per cent. The next slide exhibited the micro-structure of the rail showing the fairly even interlocking structure as between the ferrite and the pearlite. In the next slide he brought before the Institution a diagram of ten old rails, the time of life varying from 22, 24, 23, 25 years to 17, 18 and 19, etc., years. One column gave the average loss in weight in pounds per yard per annum. It also showed the chemical analysis. The average carbon of the set was 0·40 per cent., which had worn an average life of 21 years, and the average loss in pounds per yard per annum was 0·324. The manganese was 0·51 per cent., the tonnage was 40 per square inch, the elongation 25·15 per cent. in 2 inches, and the reduction of area 37·65 per cent. He next introduced to the members the good results that were obtained in rails of medium carbon and medium manganese of the following composition. The first slide showed the micro-structure of a rail; carbon 0·38 per cent., silicon 0·04 per cent., low phosphorus and low sulphur, and manganese 0·67 per cent. The same interlocking structure was seen, about an even proportion of the mass being composed of pearlite and the other part of ferrite. The next slide showed another type of the same class of rail; 0·38 per cent. of combined carbon; 0·80 per cent. of manganese, with the impurities as low as practicable. The structure was similar to that shown in the preceding slide. The slide which followed showed the structure of rails of high carbon and high manganese and the inferior physical results yielded by them. The carbon was 0·45 per cent. and the manganese 1·21 per cent. The structure was altered considerably by the excess of manganese; the crystalline areas were enlarged and ran together. The presence of manganese beyond 0·85 per cent. appeared, from a number of observations he had made, to throw the carbon areas very much

Mr. Andrews.

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Mr. Andrews. together and cause considerable lines of weakness along the pearlite areas. There was not that evenness in the interlocking structure that was shown in the rails previously shown on the screen. The sulphur and phosphorus would be about 0·06 per cent. There were no excessive impurities in the rails. Another slide also showed the type of high-carbon and high-manganese rails, and exhibited the uneven distorted kind of crystalline structure. The rails were new rails. The next slide was a Table which contained the results of the chemical analyses and physical tests of a very large number of high-carbon and high-manganese rails, the average being 0·451 per cent. of carbon and manganese 0·993 per cent. The maximum stress was 43·3 tons per square inch, and the elongation only 14·22 per cent. He wanted to draw especial attention to the Table because the tests were taken over a quantity of something like 50,000 tons of rails to show the effect of more or less carbon and manganese. The next slide exhibited results obtained with medium-carbon and medium-manganese rails. The carbon was about 0·39 per cent. and the manganese 0·78 per cent., the tonnage 39·37 tons per square inch, and the elongation 22·6 per cent., so that the reduction of only about 0·2 per cent. of manganese and 0·06 per cent. of carbon from the former case had increased the elongation to 22·6 per cent. That, he thought, was very conclusive evidence that the physical properties of steel rails were very materially affected and reduced as regarded elongation and contraction of area by the addition of manganese beyond 0·85 per cent. and carbon 0·43 per cent. as a maximum. The next slide showed a rail typical of the effects of metalloid impurities. It was also a high-carbon rail with a considerable percentage of sulphur. The effect of that was to induce minute transverse cracks which could be seen on the face of the rail. They would be not more than perhaps $\frac{1}{32}$ inch apart, but he had counted on a rail face about 14 inches in length no less than 188 of those transverse cracks, any one of which might produce the destruction of the rail under the impact of its ordinary wear. Another slide showed the face of a rail in which there was sulphur not exceeding in one part of the rail 0·09, but in other parts of the rail the sulphur had gone up to as high as 0·21. The effect of that had been to cause a number of minute transverse cracks across the rail, which led to the fracture of the rail after a comparatively short life. The last two slides were typical of the evil effects of having sulphur beyond 0·06 per cent. In some cases the physical tests were inadequate to find out the causes of fracture, but the chemical and microscopical tests combined generally showed the

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cause of the failure of a rail. Medium-carbon and medium-manganese rails gave in the mass fairly good results, with elongation about 22 per cent. and tonnage of about 39 tons to 40 tons. Several parts of a fractured rail were tested physically, but nothing could be found out from the physical tests about the cause of the fracture. The chemical test at once showed it. He wanted now to point out the evil effects of sulphur, and the way it manifested its presence at a high magnification in rail section. He exhibited a slide showing a high-sulphur rail which broke after 3 years' wear, and the sulphur was found as sulphide of iron segregated among the crystalline particles of the steel in the manner shown. There was no proper metallic cohesion in the rail. The fracture once starting under vibration would easily run along in that direction. The proportion of sulphur would be about 0·09. The next slide showed a length of the wearing face with a transverse weakness. There was no effectual metallic cohesion transversely. He did not know that he had anything further to add, except to say that he hoped before long to present to the Institution a more detailed account of his prolonged investigations, and he should be able then to go more fully into the matter than he was able to do in a discussion like the present. He had brought the slides forward with a hope that they might help to throw a little light upon the important question of the loss by deterioration in steel rails, and assist engineers to predicate a safe specification for the future that would prevent any calamitous results arising from defects, either chemical or physical, in steel rails. He could not agree that the use of nitric acid for etching steel was not to be recommended, because in his own experience, with suitable dilution according to the nature of the steel or iron to be etched, nitric acid yielded equal and even better results than the method referred to in the Paper. The etching method employed was, however, simply one of choice on the part of the operator. Dr. H. Clifton Sorby, F.R.S., the founder of the science of micro-metallurgy, had used the nitric acid etching method most successfully, and Professor Arnold and others had obtained excellent results with this process. Useful information might be afforded by the microscopic examination of steel rails at a magnification of 100 and 150 diameters; but it was desirable, in order to fully grasp the nature of the crystalline structure, to use a magnification of about 300 diameters, and in some cases even much higher. He had frequently pointed out[1]

Mr. Andrews.

[1] *Engineering*, 1897 and 1898; also in reports to various railway companies.

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Mr. Andrews. that the "interlocking" structure, as between the ferrite and carbide areas, or pearlite, was the most suitable micro-structure to ensure durability and safety in steel rails.

Mr. Jenkin. Mr. C. FREWEN JENKIN exhibited a series of photographs which he had prepared with the express object of showing the effects of different methods of polishing. The photographs were all taken from the same piece of steel, which was a piece of specially pure 0·53 per cent. carbon steel, kindly given to him by Professor Arnold. He used three methods of polishing. The first was that recommended by Professor Arnold, namely, polishing on kid skin, dry, dusted over with a little rouge. That had the effect of colouring the ferrite a light red and leaving the carbide with a bright polish. The second method was the Osmond method, used by Sir William Roberts-Austen, polishing on cloth or parchment wetted with water or a solution of liquorice. The result of that form of polishing was to wear down the soft ferrite, leaving the carbide standing out in relief. The third and most frequent method was etching in dilute nitric acid. That had rather a complicated effect, a sort of electrolytic effect, whereby a black hydro-carbon was deposited round the edges, forming a picture in black paint surrounding the actual structure in the steel. The first photograph, Fig. 22, Plate 4, was multiplied 400 diameters. The white lines showed the polished carbide, the whole areas covered with the white lines being the carbide areas referred to by the last speaker. A part of the last multiplied 600 diameters was shown in Fig. 23. The dark portion was that part which was tinted by the rouge. The same steel polished by the Osmond method was illustrated in Figs. 24 and 25. The whole of the area was of course bright steel, and it was somewhat difficult to photograph, as there was no contrast in the colours, but the ribs of the hard carbide would be seen standing out in relief on the worn ferrite. The effects of etching in nitric acid were shown in Fig. 26. That method gave the strongest contrast, and therefore was the easiest to photograph. But what was actually seen was, not the steel itself, but a deposit of hydro-carbon on the surface of the steel. It was somewhat important to observe the difference in what was being actually seen in the three cases. By the Osmond method nothing but the steel itself was seen; whereas by the other methods, in the first was seen rouge, and in the second hydro-carbon. That was the very great advantage of the Osmond method. With regard to the crystalline structure which Professor Arnold said was not shown, it was perfectly well known that all that was necessary to show the crystalline structure was to

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polish a little longer, and the Osmond method then showed it beautifully. A sulphur flaw multiplied 700 diameters, polished by the Osmond method was shown in Fig. 27. The dark area in the middle and the small pieces scattered about were the actual sulphide of iron. In such cases the Osmond method had a great advantage over Professor Arnold's method. The actual sulphur could be seen, but in Professor Arnold's method the sulphide all fell out, and all that was seen was a hole filled with rouge. Mr. Jenkin.

Mr. J. A. F. ASPINALL submitted four photographs which were exhibited, showing presence in locomotive steel tires of the surface cracks that had been referred to during the discussion. The first, Fig. 28, Plate 4, showed the vertical cross section of the tread of a tire from an engine of the Lancashire and Yorkshire Railway, showing depth of surface cracks. The surface of the tread showing cracks running across the tire was illustrated in Fig. 29; and Fig. 30 exhibited flaws produced by slight bending, which had developed from surface cracks on the face of the tire. Fig. 31 showed the polished and etched section of the structure of the metal. Mr. Aspinall.

Mr. T. R. JOHNSON had, for the past 3 years, been associated with Mr. Andrews in the investigation of the properties of new steel rails; his part of the work having been confined mainly to carrying out the falling-weight tests which Mr. Kirkaldy had somewhat deprecated in the Paper. Notwithstanding the criticism that had been made upon that old-fashioned and somewhat crude weight-test, he thought it was of real value to railway engineers, and he should be exceedingly sorry to see it abandoned for the simple bending stress which had been applied by Mr. Kirkaldy. He should like to refer first to what Mr. Andrews had already said with reference to the composition of steel rails. From the analyses Mr. Ross had supplied, Tables I–III, pp. 184, 185, showing the chemical combination of a rail which was described by Mr. Kirkaldy as probably an ideal rail, it would be noticed that the combined carbon would come in the category of Mr. Andrews' low carbon rails, that the manganese was also exceedingly low, and that the sulphur was moderately low, but the phosphorus exceedingly high. No rail-maker at the present day would like to see phosphorus at anything like that percentage. He wanted to bring under the notice of the Institution a second rail, about which he knew something, a rail taken out of the main line of the Great Northern Railway in the year 1896, having been put down in the year 1878, and Mr. T. R. Johnson.

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Mr. T. R. Johnson.

therefore having borne the heavy traffic of the main line for something like 18 years. The rail had been already referred to by Mr. Andrews. The surface was exceedingly pitted, as if the rail was suffering from smallpox. The chemical analysis of that rail was as follows: The combined carbon in the rail-head, 0·35 per cent.; in the foot, 0·36 per cent.; in the web, 0·37 per cent.; or an average of 0·36 per cent. The silicon in the head, 0·06 per cent.; in the foot, 0·059 per cent.; in the web, 0·07 per cent.; giving an average of 0·06 per cent. The manganese was 0·77 per cent. in the head; 0·75 per cent. in the foot; 0·79 per cent. in the web; with an average of 0·77 per cent. The sulphur was 0·08 per cent. in the head; 0·08 per cent. in the foot; 0·072 per cent. in the web; or an average of 0·077 per cent. The phosphorus was 0·05 per cent. in all three parts of the rail. That, he ventured to think, was almost an ideal rail. It had borne, during the 18 years it had been in the road, traffic of an estimated tonnage of not less than 100 millions. That was certainly within the mark, because it took no account of special trains and only gave the result of booked traffic. Probably he should be nearer the mark if he were to say that it had carried 120 millions of tons. It was taken from the up road on a gradient of 1 in 220 rising with the load, and, therefore, it had been subjected, not to the traffic of empty wagons merely, but to the traffic of full coal wagons coming to London. The amount of wear in lbs. per yard was 5 lbs. during 18 years, and the amount of abrasion was in depth about $\frac{3}{16}$ inch. The physical properties of that rail were very interesting. He had no doubt the members noticed that the interlocking formation, described so well by Mr. Andrews, was present in the rail. In the rail-head the maximum stress was 35·36 tons; the elongation in 2 inches was 31 per cent.; and the reduction of area 43 per cent. In the bottom of the rail the maximum stress was 35·98 tons per square inch, the elongation 32 per cent. in 2 inches, and the reduction of areas was 45·4 per cent. The microscopical examination showed that the carbide of iron areas were evenly and proportionately distributed throughout the white ferrite mass of the steel in the general interlocking formation best calculated to insure resistance both to abrasion and sudden shock. The original weight of the rail was only 80 lbs. per yard. It seemed to him that rails of that class gave something to go upon with reference to the composition of new rails at the present time. Surely railway engineers needed nothing better than something of that sort, and if it was fair to argue from the known to the unknown, in that case,

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if they could depend on getting a composition of the kind in new steel rails, surely they had got something which would give a satisfactory wear in the future. It was impossible to say of course what the wear of the present steel rails would be, because there were many questions to be taken into account. He reminded the members that 20 years ago it was the custom to hammer the ingots before rolling took place. In consequence probably of the expense involved that practice was abandoned some years ago, and now the makers were in the habit of cogging rails before rolling them, and in that way, as they said, getting the same amount of mechanical work on to the ingot as was got before by hammering with a steam hammer. At any rate, whether that was so or not, he did think it was one phase which should be borne in mind very clearly. His own opinion very strongly inclined to the belief that one of the reasons why the old rails had worn so exceedingly well in certain cases was because of the fact that a very large amount of mechanical work was got on to the ingots by the process adopted then. It was perfectly true that by the present method of cogging, a large amount of mechanical work was got on to the ingot, but he did not think nearly as much as might be obtained by other means. At any rate, he thought it was important to bear the matter in mind, and it would probably be well to specify that the ingots from which rails of large sections were rolled should be of a certain size so as to ensure as much mechanical work as possible being got upon the rail length before it was cut into the finished lengths. That, of course, could be done by indicating that the ingot was not merely to be lengthened, but that it was to be increased in thickness in both directions, so that as it passed through the cogging mill, it should be more knocked about, the rolls being properly and carefully drafted. In that way he fancied very important results would accrue in connection with new steel rails. The influence of manganese upon the physical properties of steel rails had already been referred to by Mr. Andrews, and he should like to say one word more about it. Looking over a very large number of results, something like 500, which covered perhaps 50,000 tons of rails received during the last 3 years, he noticed—taking the other components of the rails, carbon about 0·40 per cent., silicon at about 0·08 per cent., phosphorus and sulphur at about 0·06 per cent.—that for every 0·1 per cent. that the manganese went up above 0·80 per cent., the elongation decreased by about 3 per cent. in 2 inches. If therefore it was important to obtain satisfactory physical results in connection with new steel rails, he thought that the manganese

Mr. T. R Johnson.

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Mr. T. R. Johnson. should never get very much above 0·80 per cent., and judging from the experience that one had been able to gather during the long series of experiments to which he had referred, if a medium carbon and medium manganese rail could be obtained, a reliable rail would be secured and he thought also a durable rail.

Mr. Cruttwell. Mr. E. CRUTTWELL desired to refer to the comparative wear of rails when supported in different ways. For instance, whether a rail supported on chairs deteriorated more quickly than a rail laid on longitudinal sleepers, or than a rail laid on cross timber sleepers without chairs. He thought if the Author could give information on that point it would be useful. In his Paper Mr. Kirkaldy advocated a greater depth in the rail. He quite agreed with him in that, and hardly thought that the rails had advanced to such a pitch of perfection as some remarks made by Mr. Inglis would seem to indicate, in which he laid more stress upon the bearing area of the sleepers than on the depth of the rails. He certainly thought that in many rails greater durability would be obtained by increasing the depth, especially in rails that were supported underneath the heads on chairs. Such rails might often be considerably deepened with great advantage and without increasing the weight, because often the web was made thicker than necessary. With flat rails one could not go to such an extreme in the depth, as they had to rely more on the width of their base and the holding power of the spikes to resist the canting due to the blow from the tires on the side of the rail. Rails supported on chairs might, he thought, be improved in that respect, and he thought Mr. Kirkaldy's remarks were very much to the point. With regard to rail joints, it was mentioned by one speaker at the last meeting that it was objectionable to place the sleepers closer together at the rail joints than elsewhere. He did not think that objection could be upheld in every case. The primary object was to make the rail at the joint as strong as between the joints, but in many cases, where the sleepers were more or less far apart, the rail could only be made as strong at the joint as between the joints by considerable expenditure of metal in the fish-plates, and where that was the case he thought there was some excuse in putting the joints of the sleepers closer together. He should much prefer to have a strong joint with unequally spaced sleepers to weak joints with uniformity in spacing of the sleepers. He had placed on the table a joint which he was using in the Orange Free State Government Railways, in which the under sides of

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the fish-plates were bearing on the sleepers; the sleepers were Australian hardwood imported into the country. He noticed that Mr. Kirkaldy was in favour of steel rails with high tensile strains, but he was not very explicit as to how high he was prepared to go. He should be glad if Mr. Kirkaldy could give his experience on that point. His own practice was to obtain steel with a tensile strain of 40 tons and an elongation of about 20 per cent. in a length of 2 inches, with a reduction of about 30 per cent. Mr. Cruttwell.

Mr. W. W. BEAUMONT was gratified that the Paper afforded confirmation of the facts and hypotheses he had the honour of placing before the Institution in 1876.[1] In that Paper he showed how it was that tires on engines and other wheels broke without any apparent cause of fracture, and often through the solid part of the tire rather than through the holes that were made for receiving the bolts by which they were held on the wheels. The remarks which had been made by Sir Roberts-Austen and partly by Mr. Andrews, and also, he thought, by Mr. Johnson, confirmed, to a very great extent, what had been previously supposed to be happening to a rail rolled by the hard steel tires in use at the present time. The stresses arising from the rolling of the rail surface by the wheels had been referred to as being only skin-deep. It was impossible to imagine that the effect on the rail of the rolling would bring about an alteration which had only skin-deep stress, but there was no doubt that the stress varied widely with the different materials of which the rails or the tires were composed. If those rails were, for instance, of cast iron, the effect of the rolling upon the actual strength of the rails—assuming them to be strong enough to resist the transverse stress due to mere weight and impact — would be to compress and gradually crumble the surface, and that crumbling would relieve the material below of the stress that otherwise, in different material, tougher and stronger, would grow, and in growing induce the small hair fractures, of which so much had been seen, not only in the sections shown by Mr. Kirkaldy, but also in some of the photomicrographs which had been thrown on the screen.[2] As to the intensity of the stress, if it was remembered, as Sir Frederick Bramwell had pointed out, that with a small amount of hammering on the inside of a piston-ring, the Mr. Beaumont.

[1] Minutes of Proceedings Inst. C.E., vol. xlvii. p. 43.
[2] British Association Report, 1896, p. 896.

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Mr. Beaumont. compression brought about would induce a lengthening stress in that material sufficient, at the small radius that it had to act through, namely, the thickness of that ring, it was obvious that the stress must be very considerable. Before leaving Sir Frederick Bramwell's remarks, he would like to say that when he saw some difficulty with regard to the proof of this stress, and the other fact as to certain wrought-iron rails which were light and narrow, he thought perhaps Sir Frederick had overlooked two facts, namely, that in the cast-iron ring he referred to, the material was not free to flow under the hammering that was done more along the middle of the width of the ring than elsewhere, as it was along the narrow rail rolled all over the surface—a tough rail which would bend pretty freely, and which would be freed from the stresses that otherwise would accrue. As an example of that—he had not the Paper in his hands that he referred to, but as far as he remembered—of all the tires that broke with holes in them, about 80 per cent. broke through the solid rather than through the hollow. The lesson from that was that the stresses brought about by the growing compression in the material of the surface not free to flow in the body of the rail, was free to flow round about the edge of the hole, and flowing in that way was rubbed off and worn off and crumbled off in the use of the tire partly by rolling and partly by the use of the brakes. The reality of that stress was, he was glad to say, confirmed by these rail tests, and the lesson seemed to be that a material should be used not necessarily of the strongest and not necessarily of the hardest. With regard to safety, one of the most important points was, he thought, to have the rails of such large section, particularly in the head, that the strength of that head as compared with the stresses that would be set up in the part rolled and compressed as described, should be enormous. In that way he thought the life of the rails might be undoubtedly a very long one. There were several points in the Paper that made it necessary to refer to the capriciousness of rail fracture, and he would say that a reference to tire fracture was perhaps better calculated to give correct notions than a reference to the rail, because the tire on a locomotive wheel had a definite base upon which it ran. The rail, on the other hand, might have between supports a distance between a pair of chairs or a distance between two pairs of chairs, and the difficulty in arriving at a conclusion from some of the figures that Mr. Kirkaldy had given as to the fractures of different rails in different places arose no doubt from the conditions under which those rails worked in that respect. There was one more

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point. The question was obviously not entirely a metallurgical one, but one of mechanics and physics as well as metallurgy. The last point he would remark upon was that the unaffected strength of the rails on curves was further confirmation of the nature of the origin of those stresses. Mr. Beaumont.

Mr. J. R. BELL agreed with the conclusions Mr. Kirkaldy had expressed, less, however, with regard to the extra carbon than about the greater depth of rail. Apart from flaws he was surprised to find that a great difference was discovered between the deteriorated strength of the top and of the bottom flanges of the rails. Taking the action to be as suggested by the counter-flexure of the rail in passing over the points of support in the chairs, it seemed to him natural that the bottom would suffer in the converse way equally with the top; the bottom of the rail would be compressed over each chair seat just as the top was pulled out. He was pleased, however, to find that the tabulated figures for tension strains did not seem to point in all cases to such a great difference as a mere reading of the Paper would imply. He had not had the pleasure of hearing the whole of the discussion, but he felt strongly that Mr. Stirling's famous "Single-driver" engines had a good deal to do with the particular effect that was produced on the Great Northern rails. The tension exercised by a driving-wheel, especially at starting, was like trying to pull the skin of the rail over its head, and it seemed to him that that was calculated to account for a good deal of the development of the hair-cracks. However homogeneous the material of a rail, or tire, might be originally (and he was far from believing all bull-headed rails above reproach in this respect) Mr. Kirkaldy rightly stated that as the original rail-skin wore, a new one was perpetually reformed by "hammer-hardening." Possibly a photo-micrograph of the rail-skin might afford a revelation similar to that of Sir William's beautiful picture of tempered steel. Precisely the same effect by "cold rolling" must occur in tires, except that there the original skin was not worn off but removed in the lathe. Mr. Aspinall's photographs of driving-wheel tires corroborated Mr. Kirkaldy's view of the rail-skin. In either case a thin skin of stronger metal was welded to a softer body, and all the tractive force of the engine was engaged in pulling the skin of the rail back, while the weight of that wheel, like all the other rolling-loads, was trying to push the under metal forward, much as a pastrycook's roller pushed dough before it. When rails "crept," or tires ran slack, these considerations, coupled with the quality of the material, might help to explain the reason. Mr. Bell.

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Mr. Bell. Whether, however, actual creep was disclosed or not, it seemed to him that these two tendencies were ever present and that their continued interaction made for the disintegration of the rail-head. The sum of these forces was in question where the rail was concerned and their difference in the harder worked tire. Either force appeared to vary directly with the weight on the tire and inversely with its diameter. Owing to greater discrepancy between the skin and the body, it was probable that a deep bull-head was more liable to disintegrate than that of a more symmetrical rail. He could not recall any serious failure of a steel rail in India, except where appreciable creep had occurred with a deep-headed rail section. It was not uncommon for a heavy express engine to deliver a tractive effort of about 6 tons on the draw-bar, or 3 tons reaction on each rail, and this stress upon a very thin skin was obviously better applied to two points of the rail and coincidentally to two tires than to one. In axles; which also acquired cold-rolled skins, a long journal was subject to counterflexures as well as plastic, "creep-like" flow, and it might be suggested that shorter American proportions of journals might avoid the troubles with hair-cracked steel journals that were far from uncommon with long journals. Whether or no Mr. Kirkaldy's fruitful suggestion, that the starting-points were the weakest spots in rails, led towards a return to double-headed rails and to inverting them at short intervals seemed almost a moot point. It might be that in this matter the present generation were not much wiser than their fathers, and it was certainly cheaper to invert rails than to anneal them.

Mr. R. Johnson. Mr. Richard Johnson desired to bear his testimony to the good work done by David Kirkaldy, and he was glad his mantle had fallen upon his son, whom he congratulated upon the Paper he had put before the Institution. He should like, if he could see his way, to speak to the practical use of the Paper. Engineers had been for a good many years past working on steel rails; his Company commenced by paying £18 a ton for steel rails, and pretty nearly ended by paying £3 12*s.* 6*d.* He was very much of the opinion of Mr. T. R. Johnson, that there was not work enough put into the ingot before rolling. When his friend Mr. Price-Williams was at Deepcar he had a steam-hammer connected with his rail plant, but he thought it would puzzle Mr. Price-Williams now to find a steam-hammer in a rail plant at all. He was strongly of opinion that if a rail was wanted to wear, work must be put into it. It should not be lost sight of that probably the weights on driving-wheels

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to-day were nearly double what they were in the year 1862 when steel rails were commenced to be used. Those engines must be punishing the rails very severely, and it struck him that that was the direction which must be looked to in connection with the manufacture of the rail. He thought work must be put into it. Mr. Kirkaldy had very properly suggested that engineers should look out for such fractures. He had to send several pieces of rail to a gentleman in the North of England, who sent him the result, with the suggestion that in future the leading platelayers should be supplied with emery paper that they might polish the surface of the rail to look for those fractures. That was not practicable, and he took very little notice of the suggestion. If rails lived as rails had lived for something like 20 years, probably, at the present price of rails, that was as much as could be expected; but he would strongly recommend that perhaps 5*s*., 10*s*., or even 15*s*. a ton should be spent on putting more work into the ingots. Mr. R. Johnson.

Mr. PRICE-WILLIAMS observed that a steam-hammer was never used at Stockbridge, in hammering the ingots for rails or any other purpose, and he thought it was only due to Mr. Fox to say that he would not allow it, and rail contracts were declined because they were required to be hammered. Mr. Price-Williams.

Mr. RICHARD JOHNSON could only add that the best rails he had ever used were made from hammered ingots. Mr. R. Johnson.

Mr. F. W. HARBOARD considered that the bending test suggested by the Author must throw very great light on the effect of wear upon rails, but he did not think that Mr. Kirkaldy's conclusion, that the head of hard rails—by which he assumed he meant rails which necessarily contained more carbon—were less likely to develop cracks, was supported by theoretical considerations, or borne out by practice. Referring to his own Paper Mr. Kirkaldy gave the tensile tests of three rails (page 142), in which Nos. 1 and 3 gave respectively 51·5 tons and 47·6 tons per square inch, and No. 2 6 tons. All those rails were what would be considered hard rails, in fact anything above 43 tons was a hard rail. A 40-ton rail was about what he considered the maximum tensile for good rail steel. Of these three rails mentioned by Mr. Kirkaldy, two at least showed the surface-flaws, which he said were not so likely to develop in hard rails, and only one, which certainly was the hardest of the three, did not. Then Mr. Kirkaldy supported his contention by referring later on to very soft rails which showed flaws and which he said gave a tensile test of only about Mr. Harboard.

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Mr. Harboard. 33 tons. That was practically mild steel, and a great deal of bridge-steel gave from 28 tons to 32 tons, and nobody would suggest that rails should be made as soft as bridge-steel. He had been trying some bending tests with the assistance of Professor Hearson, who had kindly made them for him. The test was suggested by Mr. Stead some time ago. At Coopers Hill there were not the facilities for bending rails in the same way that Mr. Kirkaldy had done, and he had been in the habit of cutting a piece off the head from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch or more, as the case might be, taking care for comparison that they were all the same thickness, and bending them in compression and extension, and he had tested six rails in this way and the results varied very much. In one case a rail which was very soft, containing about 0·34 carbon, after 19 years' wear, bent over practically to the same extent both in extension and compression and showed no surface cracks. In the case of a hard rail containing 0·6 of carbon, which had only been down two years, the head in extension gave evidence of considerable hardening, as shown by its bending considerably more when tested with running surface in compression. There was one other point in Mr. Kirkaldy's Paper he wished to refer to, and that was whether some of the surface cracks might not possibly be due to sulphur in the rail. It was well known that with a certain amount of sulphur in a rail, during the rolling little incipient cracks were formed which would not be visible, but which might develop with cold work. With regard to the question of the analysis it was very important that railway engineers should realize there were two classes of constituents in steel, those which were essentials like carbon and manganese, which the manufacturer had to vary according to the mechanical tests the steel was required to stand, and those which like sulphur and phosphorus might be regarded as impurities pure and simple. It was distinctly advisable to consult with the manufacturer as to the proportion of carbon and manganese necessary, and these should then be specified within such limits that the mechanical tests could be readily obtained in ordinary work, but with regard to sulphur and phosphorus these were not required and need never be high, provided pure materials were used and care taken in the manufacture. High phosphorus or sulphur either meant impure materials or bad workmanship, and the engineer might reasonably ask to be protected against these by specifying that they should not exceed certain limits for different classes of steel. He thought it was in the interest both of steel makers and engineers that the latter should specify that the impurities other than carbon

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and manganese should not exceed certain limits and so ensure a high-class material being obtained. Mr. Harboard.

Sir WILLIAM ROBERTS-AUSTEN, in reply, said that, generally speaking, a micro-section cut from the head of a rail did represent very fairly the general structure of that rail, but the extent to which differences occurred he attempted to show by the section of the rail provided by Mr. Kirkaldy, of which he exhibited several sections. It might be perhaps remembered that the portion taken from the web differed from the rest in having its structure elongated; but speaking generally, one section represented the whole rail very fairly. He had very often attempted to get sections at right angles. A rail, as he said, resembled a rock, that was, the pearlite and the carbide, being as it were, the mica of the granite. If a longitudinal section was taken there was some different geometrical relation between the pearlite and the ferrite that would be found in the mica and quartz of a distorted granite, but not to any very great extent. That structure obviously went through the entire rail, exactly as the same structure was found, speaking generally, in a mass of granite. He had found many cases in which the fracture crossed indifferently both the ferrite and pearlite area. On the other hand, he had found some cases in which, as Mr. Andrews very justly said, the fracture followed the lines of the pearlite. With reference to Professor Arnold's remarks, he would point out that the title of his Paper was the photo-micrography of steel rails, and in stating that this question had not been previously brought before the Institute, he did not contemplate drawings of micro-sections, in which form the question of steel rails had been previously brought before the Institution. In answer to Mr. Andrews, he was in some little difficulty, because although Mr. Andrews' contribution to the discussion mainly dealt with photo-micrography, he did not discuss his Paper. Therefore he was in some little difficulty in knowing how far they differed, or whether they differed at all. So far as he knew they only differed in one point, namely, that he vastly preferred photographs and Mr. Andrews preferred drawings. The members had seen the photographs that Mr. Frewen Jenkin had thrown on the screen, and it was not for him to say which were preferable, drawings or photographs. He merely said that he infinitely preferred photographs. Photographs could easily be obtained which would reveal all that a drawing could be made to show. With regard to Mr. Frewin Jenkin's most interesting communication, he should just mention that Osmond's method was not the only method he employed, but he had purposely limited Sir William Roberts-Austen.

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Sir William Roberts-Austen. the range of his communication by saying in the Paper "that the consideration of the subject had in the present notes been restricted to the narrowest possible limits." References to slag flaws or to sulphur flaws had been omitted, as it was desirable to direct discussion of the subject mainly to the question of the relative areas of pearlite and ferrite. Had he wished to show the sulphur flaws or the slag flaws, he could have done so with the greatest ease, he should have etched the specimens differently. He agreed with Mr. Frewen Jenkin in thinking that Osmond's method was infinitely preferable to the other methods which had been mentioned. Mr. Inglis had asked him whether "hammer hardening" might alter the rate of expansion in different parts of the rails. He considered that such would probably be the case, and that the subject well deserved attention. Mr. Inglis had also referred to the question of fineness of grain, and Sir William would point out that some time ago Mr. Osmond and he had shown [1] that in certain crystalline alloys annealing at what seemed to be an inadequately low temperature produced fineness of grain. It might, therefore, be well, with this object in view, to heat a rail (before its rolling was finished, or after) to a temperature below that at which the carbon of the pearlite would diffuse into the ferrite.

Mr. Preece. Mr. W. H. PREECE, C.B., President, thought some of the members would like to have Sir William Roberts-Austen's opinion on a certain point. From the photographs and drawings it would appear that steel rails were rather a mechanical mixture, as he could see Sir William believed, because he referred to granite as being a kind of analogous substance. Did Sir William think there was a line of cleavage through the rail similar to lines of cleavage met with in rocks like granite?

Mr. Harris. Mr. GRAHAM HARRIS desired to supplement that, and to ask was the line of cleavage, if it did exist, affected by the "work," and the manner in which the work was put upon the rail?

Sir William Roberts-Austen. Sir WILLIAM ROBERTS-AUSTEN said the whole object of his communication was to draw attention to the fact that a steel rail was not a uniform material—that it was in fact a solidified solution of carburized iron from which certain constituents, mainly the pearlite, that was the carbide, had separated out as the mass cooled down. Had the rail been quenched, there would have been a more or less glassy uniform material, which

[1] Philosophical Transactions of the Royal Society, vol. 187 (1896), pp. 417–432.

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might possibly show cleavage. In his belief, though it did not rest on accurate experimental evidence, there were no true cleavage planes analogous to those found in slags or other rocks. Sir William Roberts-Austen.

Mr. W. G. KIRKALDY, in replying, said it was unnecessary to say how very gratified he had been by the reception of his Paper, and he mentioned especially the personal gratification he felt from the very kind remarks with which the President introduced the proposal for thanks, coupling it with his father's name. He felt it a great honour and a great responsibility to follow in his footsteps, but he was doing his best to keep up the traditions that he had set for him. A sketch of how the Paper started might be interesting. He had written it in quite a tentative manner. He had not attempted to deal conclusively with the subject; it was much too complex. But he did his best, first of all, to show the tests that he had been able to make, which he thought would simplify the matter somewhat; that was, to provide fairly simple mechanical tests by which an engineer could judge of the deterioration which had taken place. That was the point from which he had started, and he thought the method of the duplicate bending test afforded a means of judging what deterioration was set up in a very practical and simple way, and one which could be followed out at any works. He also wished to point out that the difficulty with tensile tests was that the experimenter often did not hit on the deterioration which might exist in the rail head. He fancied that might have been overlooked in previous years in making mechanical tests. Often in a rail which might be in a defective condition very good physical results were obtained. But that was owing to the nature of the tests; in a tensile specimen the top surface of the rail could not be included. He thought that was overcome by the bending test in the inverted form. If there was any deterioration it was discovered. Testing it in the normal way gave a fairly ready practical method of judging what the rail was originally. The records could not be referred to to show the original condition of the rail, but he thought the bending test gave that sufficiently close. With regard to Sir Lowthian Bell's glass experiments, he thought they rather proved his case. Glass afforded a sufficiently near illustration for steel. When Sir Lowthian Bell had the glass loaded in the centre and a very slight scratch underneath it showed what a remarkable falling off there was in strength, it did not seem to occur to Sir Lowthian Bell that a similar thing took place in a rail through looking at it from the point of view that the head would be always in compression. The trouble was that the head was not Mr. Kirkaldy.

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Mr. Kirkaldy. always in that condition. It was constantly varying; as the load shifted along, the point in compression a moment before became in tension owing to the deflection of the rail as the wheels travelled along. Therefore the glass illustrated rather well how, if any mechanical flaw started in the rail head, it was of serious moment. He would have been very pleased to have seen some photo-micrographs of some of the flaws he had shown in the rail head. He had called them hair cracks. If it could be found by means of the microscope whether the cracks followed any line of cleavage it would be of great assistance. It occurred to him that if it went straight across regardless of the structure, it would point rather to being a mechanical trouble. If the microscope proved it followed the interlocking lines, then if the metallurgist could give a structure of steel more interlocked, he thought it would last better under practical conditions. It was not at all surprising that Sir Lowthian Bell should have found the question of breakage of rails such a very complex and contradictory one, because by ignoring mechanically induced flaws as of no consequence, and therefore endeavouring to explain breakages merely from the chemical standpoint, many inexplicable cases would naturally be found. This illustrated the advisability of examining cases of breakdown from a mechanical as well as from a chemical standpoint. He sympathized with Sir Lowthian Bell's remarks as to the low prices obtained for steel rails; this was a point which he had discussed with several engineers, namely the advisability of paying a somewhat higher price per ton in order to secure a better quality; for instance, to provide for more being cut away from the crop at top end of each ingot, because so many failures at the ends of rails were undoubtedly due to insufficient metal being cut away. He had deemed it better to let information regarding chemical composition be added subsequently, by those who had special experience in that department. The results of chemical analyses had been incorporated, however, in several instances on the manuscript reports which accompanied the Paper, and which might be consulted in the Library. The few Tables printed as Appendixes were merely to illustrate the method of reporting results on the tests, and especially the marked difference between the inverted and normal direction of bending tests, but these Tables gave only a meagre idea of the extent of the experiments. The manuscript reports contained over 230 separate experiments, which again were selected as the more interesting among a still larger quantity. It might be of interest to give the analysis of the piece of rail

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from which Sir William Roberts-Austen had prepared the fine series of photo-micrographs shown in Plate 3. Carbon 0·520, silicon 0·043, sulphur 0·109, phosphorus 0·049, arsenic 0·035, manganese 0·360, copper trace, iron 98·884. The tensile strength of the bottom of the rail was 45·6 tons, contraction of area at fracture 29·1 per cent., extension in 10 inches 14·7 per cent. Mr. Snelus's question whether the cracks were developed in flange-rails to the same extent as in bull-headed and double-headed rails raised a very interesting point, but one which, up to the present, he had had no opportunity of investigating, so could not express any opinion. He would mention in passing, however, that if flange-rails were used the edges of the flanges ought not to be notched for the spikes. When investigating the cause of breakage of a number of flange rails, he found that in every case failure had occurred, not from the top or head as those shown in the Paper, but from a flaw induced in the flange at the angle of the spike-notch (which in those instances were all cut out square, with sharp corners). If notches must be employed with that class of rail to prevent "creeping," such ought at least to be rounded out so as not to leave any sharp corner. This was mentioned merely to show how very sensitive steel was to any detrimental form. The remarks of Mr. Inglis as to American engineers having adopted standard sections for rails was an interesting indorsement of the views advocated by the late Mr. David Kirkaldy. There was, however, another very important part of Mr. Kirkaldy's scheme, namely not only to fix upon definite standard sections, for a regular series of weights or sizes, but further that a standard quality of steel as to mechanical tests, &c., should be agreed upon in order that rail makers could, in time of slackness, roll rails for stock to keep their mills going, and under such conditions in all probability produce more uniform and better grade rails than when heavy orders had to be pushed through at a great speed, hardly giving time for proper inspection and entailing much more extensive plant, &c. His idea being that makers should be enabled to work under as uniform and as regular conditions as could be devised. There was much to be said in favour of these views even at the present time, and he trusted that standard sections and specifications would be attained. Mr. Inglis's remarks as to increasing the width of the head of a rail were well worthy of consideration, especially if the increase in width were made use of to increase the bearing for the tire, which would economise the turning up of same and also render the effects of the traffic less severe upon the rail. He did not object

Mr. Kirkaldy.

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Mr. Kirkaldy. to the drop test in its proper place and used for its legitimate purpose, namely, the testing of new rails to determine rapidly whether they be suitable, and to weed out defective rails, where the engineer was more anxious to avoid brittle or defective rails than to know exactly the quality. He agreed that from this standpoint the drop test was useful, yet its tendency was always towards the favouring of a softer steel. But when commencing his investigation as to the effects of wear upon rails he considered that to attempt to ascertain data as to the extent of the deterioration set up in rails by means of the drop test would be practically wasting time, and he therefore inserted his views in the Paper. He was open to conviction, however, and would be glad to have the privilege of witnessing any tests in this direction upon worn rails, where any engineer found that he could determine the degree of deterioration. The static or pressure tests in the examples brought forward were sufficient not only to show the presence, but to gauge the relative extent of deterioration very closely. In the cases of some worn rails tested by the Author, of which portions were also tested under the tup or falling weight, he found that the rails which withstood his inverted bending test satisfactorily also withstood the falling-weight test; while in the case of a rail which was reported unsatisfactory under the falling-weight test a similar result was shown by the Author's pressure test. It would be highly interesting to be able to carry out comparative tests in this direction on a more extended scale. Mr. Inglis mentioned that a 95-lb. or 100-lb. rail provided a sufficiently strong girder for all requirements; this was readily granted, but the whole tenour of the Author's views had been rather to endeavour to improve the grade of steel and keep down the weight, as it appeared open to question whether longer service would be obtained from the heavier sections. If weights were increased and relaying was carried out upon a wide scale the question was merely postponed for many years, but it was a very costly matter in the meantime. Moreover, had it been proved as yet that the present rails were too weak, or that the bulk of them were to any extent in an unfit condition? In reference to the instance which Mr. Inglis mentioned of his increasing the number of sleepers per rail under certain conditions, he thought the better the condition in which the road could be kept the better for the rail. If full information could be obtained in cases of rails failing he believed that it would be found in many instances that the road had been in poor condition, entailing abnormal deflection in the rail, and so accen-

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Mr. Kirkaldy.

tuating the effects of the traffic. His suggestion of deepening the rail would tend to ameliorate such conditions, but with the increase in rolling loads it was possible that a larger sleeper area as well would prove economical in maintenance. He was much indebted to Mr. Ross for furnishing the results of analyses of several of the rails dealt with. Regarding the Table computed from ten different analyses of the same rail showing the extremes and mean results, he thought that the wide divergence shown in some of the constituents might be due to difference in making the analyses, and not entirely to difference in the steel. The analyses (Table II, p. 170) of the hardest and the softest of the six rails, taken from the line near Misterton, were of special interest, as 50½ million tons had passed over those rails, and yet there was no appreciable deterioration set up. The tensile strength of the hardest was 45·4 tons, contraction of area 36·4 per cent., and extension in 10 inches 18·8 per cent. In the Author's opinion the chemical composition as to carbon and manganese was noteworthy. With reference to Table III, giving analysis of what was termed an "ideal" rail, he felt some doubt as to the phosphorus being really as high as the proportion given, as such was scarcely compatible with the physical qualities. The cuttings for this analysis had not been supplied by the Author, so there might be a possibility of the analysis representing another rail. He might emphasize perhaps one part of his Paper which had not been fully kept in view. He thought it was very important to know the conditions under which each rail was used. He could classify it almost in this way: if the conditions were favourable, a straight line and no stoppages, he believed practically any grade of steel within moderate range would give satisfactory results. There was one which he showed, which he termed an ideal rail, and he thought he must still adhere to that in the sense in which he meant it. It had had 23 years' main-line traffic on the Great Northern Railway, and under the bending test it practically showed no deterioration whatever. Chemically, it might be that it was not an ideal rail. He thought in considering the question it should be brought down to a narrow compass by looking for the steel which would stand best under unfavourable conditions. He thought the steel made at present sufficiently answered all purposes where the conditions were favourable. He thought there need be no alarm felt about it. The chances were that the flaws were only induced under severe conditions, and the point which might be followed up with most benefit by railway engineers who cared to go into it would be the effect of the starting-action or the

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Mr. Kirkaldy. skidding-action. He thought a great deal in the behaviour of rails depended on the mechanical conditions under which they had been made. Possibly more lay in that even than in the range of the chemical constituents—whether the right amount of work had been put into the rail and at the right heat. He thought it should be investigated; what differences arose, say, from casting the ingot, then letting it soak in the pit, and cogging it and rolling it right away. Did that give a different steel from one which in the older days would be allowed to cool off, then be re-heated, possibly hammered, or just cogged and rolled? He was rather afraid of obtaining hardness by high carbon, and he thought it would not be wise; his feeling had been for a rather moderate carbon. To obtain hardness by manganese seemed the readiest way. Mr. F. E. Robertson criticized the use of the term "stress" in the bending tests; this term had always been perfectly well understood by engineers to whom reports upon experiments had been sent in all parts of he world during so many years. There did not appear to the Author to be any valid ground for misconstruing the terms employed; had the words "stress in pounds" referred to stress produced in the bottom of the rail by the imposition of another load it would have been properly described as such, and both amounts duly stated. Mr. Robertson seemed to have overlooked the extensive manuscript Appendixes contributed with the Paper, which might be consulted in the Library. It was the custom of the Author's firm to arrange test results in the order of merit wherever practicable, but the originals of these few reports were not thus arranged, being exceptional, and it was not considered necessary to rearrange them for the purpose of the Paper, as they were printed in the Appendix merely to show contents of reports. As regarded the views he expressed, that "it seemed *à priori* not unreasonable to suppose that a harder steel would resist better the local action of the wheels than a softer steel, and so escape the incipient flaws which ultimately led to fracture," he agreed that a harder and tough steel would stand better. If the conditions of the modern wheel-loads and the small base or area of contact upon which the tire bears were realized, the actual compressive stress upon the steel was very high. It was very difficult, almost impracticable, to define the extent of bearing area, as the conditions varied greatly between various-sized wheels, tires in different condition as to form, and whether the rail had a slightly- or much-rounded top. Certainly the pressure imposed on the rail-head was very severe. Now if the rail be of soft steel the metal could not withstand this

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pressure, but yielded and flowed, in many cases working out over the edges of the top in a thin scab or fold, and it was during that severe process of cold rolling and beating out of the top that there appeared to be the real risk of induction of the hair-cracks which he had shown. On the other hand, if a harder, but at the same time tough, steel be employed it would not be disturbed so much under the pressure imposed, and therefore it was quite reasonable to expect that less change should be produced in the metal. It must be carefully borne in mind that in advocating a somewhat harder steel than usually employed he did not intend mere hardness, but rather a stronger and tougher steel. It should also be borne in mind that it did not necessarily follow that because in the past rails of moderate hardness had worn well in practice that new rails of similar grade would do the same in the future. In the past, at the time when some of the aged rails were laid, the wheel-loads were much less than now; in course of time the heads of those rails became gradually planished or hammer-hardened, practically representing a harder steel. This hardened top once formed, when free from induced flaws, had sufficed wonderfully well for resisting the action of the heavier modern wheel-loads; but he thought that if in new rails it was attempted to reproduce (because it was open to question whether the modern rolling of rails produced an equally good mechanical or physical condition of the steel) the steel of say 20 years ago, it might be found that the intensity of the traffic would punish such medium grade steel very rapidly, and once induced flaws were set up the life of a rail became most uncertain and erratic, and notwithstanding that the section might be made much heavier the final life might prove very disappointing. It was with these ideas that the Author thought it prudent to aim for a harder yet tough steel, and that special care be taken in all the stages of rolling to toughen the steel mechanically as far as practicable. He might adopt Mr. Robertson's simile or illustration of the matter of wire-drawing only he felt it scarcely applicable. In drawing wire the harder grade doubtless had to be annealed more frequently for practical considerations to render it workable and permit of its being drawn down smaller until the required size be reached, the final produce being a very fine material. Now, if it were practicable to finish rails by a similar cold-drawing process he believed that it would place the steel in a much better condition for resisting the induction of flaws, as well as obtaining greater wear-resisting capacities. In other words, if such process could be done during manufacture the rail would be better, being in such case more

Mr. Kirkaldy.

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Mr. Kirkaldy. homogeneous throughout than was the case at present, where a softer rail had its top surface only beaten into a hard dense skin which was merely dead hard but deficient in toughness, and was therefore not in a favourable condition to accommodate itself to the movement or spring in the rail during the passing of trains. He was obliged to Mr. Robertson for bringing forward the interesting information regarding American practice in the matter of specifications for chemical composition of rails. It appeared as if the high carbon specified for the heaviest sections was a short-cut, so to speak, to obtain wear-resisting steel without putting so much work upon it during rolling. It would be very interesting to know the dimensions of the ingots used for producing the 100-lb. rails. It should be preferable or safer to make sure that with heavier rails they received the same or even a greater proportion of work in rolling by insisting upon having the cross dimensions of the ingots sufficiently large. This was only mentioned as a suggestion, as it appeared on the face of the specified analysis as if hardness were being obtained in America in the direction of mere "chemical hardness," which was not what appealed to the Author when forming his conclusion that the direction for improvement tended toward a harder steel. He was gratified by the kindly manner in which Professor Arnold had offered to carry out micrographical examinations upon samples of worn steel rail, and he hoped to avail himself of such kind co-operation in the cases of special interest. He trusted that in the future there might be opportunities for carrying further this investigation upon rails carefully selected from defined positions and of ascertained duty, in one direction giving the preference in selection to rails which had behaved the best under long service, and in the other direction selecting the rails which had behaved unsatisfactorily, with a view of determining what to avoid and, on the other hand, what to aim at in making new rails.

Mr. Preece. Mr. W. H. PREECE, C.B., President, thought the members had every reason to congratulate themselves upon an admirable, well-sustained, instructive, and interesting discussion on a most important subject. The Institution was deeply indebted to the two Authors for bringing before it Papers on such different lines. They showed what the members wanted to see a little more of, namely, the intimate connection which existed between the engineering profession and the scientific world. He had said before that the engineering profession was based directly on the facts of science, and the more the Institution could obtain scientific spirits

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like Sir William Roberts-Austen to come before it and give the scientific aspects of the questions, and other practical men like Mr. Kirkaldy dealing with such questions from the practical point of view, the more the world would see there was no separation between engineering and science. Mr. Preece.

Correspondence.

Mr. JOHN BARKER considered that Mr. Kirkaldy had shown great sagacity and skill in the experiments he had made and recorded, but he thought some of the deductions therefrom were not justified. The subject was wide and required treating on a broad scale, beginning with the raw pig-iron through every stage of manufacture to the worn or fractured rail. The large proportion of fractures found at or near the ends of rails was doubtless chiefly due to the fact that too little "crop end" had been cut off. Another cause was the fact that the earlier steel rails had the fish-bolt holes punched in them and were not rymered out. He apprehended that it was now well known that even rails of good quality were most seriously injured by punching holes in them, rendering them incapable of resisting the impact of blows. If the steel were of inferior quality the detrimental effect of punching was accentuated. The amount of "crop end" cut off varied considerably. He had found that the number of defective rails diminished in proportion as the length of crop cut off was increased. It had been his duty to witness a large number of ingots sawn through in order to ascertain to what extent they were unsound. The experience so acquired had convinced him that as a rule too little crop was cut off. The "pipe," or hollow and honeycombed portion of ingots, extended from the top to one-third or one-fourth of the length. In the case of rails all the "pipe" was rolled into the rail bar, excepting that in some cases a small piece was sheared off the bloom after the ingot had been cogged down in the roughing rolls. In other words, the impurities and honeycombed portion of the top of the ingot were "rolled in," and very little was "cut off" after the rail bar was rolled. As the rail bars varied in length between 100 feet and 200 feet, to merely cut off from 2 feet to 6 feet was insufficient to get rid of the unsound portion. The pent-up gas and impurities were largely rolled into that rail which was made from nearest the top end of the ingot. He was convinced that in many cases the cracks referred Mr. Barker.

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Mr. Barker. to by Mr. Kirkaldy were either "developed flaws" originally in the rails or cracks due to the material being of improper chemical composition, and not "induced cracks" caused by "hammer hardening," as stated by the Author. He had seen many similar cracks in channel and angle bars and in axles. In all cases they had been associated with high phosphorus or with attenuated "pipe" flaws. He could give many examples, but one would suffice. Forty-seven lattice roofing girders were found to be cracked in fifty-nine places while they were lying on the ground before being erected or put to work. The most severe mechanical tests failed to discover any weakness of the material, but the reverse; it was tough in the extreme. Chemical analyses made by various experts showed it to contain an excessive amount of phosphorus, and had chemical analyses been made prior to the girders being built the material would have been rejected. He was convinced that too much had been made in Mr. Kirkaldy's Paper of the effects of "hammer hardening." His attention had been drawn to an extensive series of experiments recently made by a leading rail manufacturer, the results of which appeared to clearly show that the deterioration of the material at the top of the rail caused by prolonged wear was very small indeed. The worn rails were made by various makers, and were collected from various railways. They had been in work an average of 16 years, and had carried an average of 100,000,000 tons over them. The average wear off the top of the heads was $\frac{1}{4}$ inch fully, and the average deflection under falling weight test 4 inches. He had suggested to the makers that they should also experiment upon successive thin layers cut off the top head. This was done and they were tested in tension. The tensile strength and extension between the top, second, and third layers varied very little in any given rail, with one exception only. The tensile strength in various rails varied between 36 tons to 46 tons per square inch, and the extension between 14 per cent. and 21 per cent. The top layer was cut as near the worn surface as possible. He wished to point out that Mr. Kirkaldy's tensile tests taken out of the top head were of too aggregate a nature, there being only a mere fringe of the upper worn surface of the rail, the lower portion of his circular test-pieces being very little affected by the wear on the head. He would also instance a case of short pieces of rails used in connection with testing cast-iron bowl sleepers. A short piece of rail about 2 feet 6 inches long was keyed in the sleeper, and a $3\frac{3}{4}$-cwt. tup was dropped on to the middle of the rail from heights varying from 1 foot to 8 feet successively. He was informed that

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these pieces of rail received approximately 6,000 blows on one spot from an average height of 5 feet 4 inches, the effect being that the rail head was depressed and spread out at the point of impact. No evidence of cracking was perceptible, and in the large number of pieces of rail used "it was a very exceptional thing for a rail to break." He thought it would also assist in arriving at the true solution of the question if a comparison of the manufacture of rails and tires were made. If tires, which were exposed to far more "hammer hardening" than rails, could be made so that they wore down to half their original thickness without cracking, why not rails? The tread of the tire received much more work upon it in rolling than the top head of the rail, and this accounted for some of the superior wearing qualities of a tire over a rail even if made of the same material. But there were two other reasons for the superior wearing quality of tires over rails: (1) Tires were made of better materials; (2) the "pipe" or unsound part of the ingots was either cut off or punched out before the ingots were becked and rolled. The whole question appeared to resolve itself into "cost of manufacture." If the price were paid sound rails could be made that would wear without cracking down to the minimum thickness permissible, as in the case of tires. He had recently referred to a specification of about the first steel rails sent to India 35 years ago. They cost £18 15*s.* per ton, the ingots were hammered and the steel was made partly of cold blast and partly of Swedish pig-iron. With respect to the question of the best percentage of carbon, his experience led him to believe in the use of rails of medium hardness containing from 0·35 to 0·45 of carbon —safety first, durability next. The Americans required harder rails than were necessary in England, because they used extremely hard chilled cast-iron wheels, which cut away the inner edge of the rails with great rapidity. They laid their rails directly on wood sleepers; this justified the use of harder rails than when laid on cast-iron chairs. In the absence of any practicable plan for making it directly to the makers' interest to produce safe rails of maximum durability, he ventured to think that the best course was to have a specification based on the latest knowledge and experience and a thorough system of testing chemically and mechanically. The micro-photographic methods of investigation were in his opinion not readily enough applied for every-day use. The output of rails was very rapid, and required a readily-applied test, such as the falling weight, which he believed was the most searching of all tests. To give a piece of rail a few comparatively light blows and gradually warm up the material

Mr. Barker.

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Mr. Barker. was wrong in principle. One heavy blow with deflection within defined limits would alone go a long way to secure good rails, but tensile tests and chemical analyses were very useful additional precautions, as material containing phosphorus might crack however well it bore tensile tests.

Sir Douglas Fox. Sir DOUGLAS FOX, Vice-President, remarked that experience with steel rails went to show that, after a life varying between 15 years with light traffic and 3 years or 4 years with heavy traffic, serious deterioration took place in the top surface of the rails, leading to microscopic flaws and to frequent fractures. He had often consulted Messrs. Pattinson and Stead, of Middlesbrough, upon this matter, and the following report from that firm might prove of interest.

REPORT ON FOUR RAILS TAKEN FROM A SOUTH AMERICAN RAILWAY, AND RECEIVED JULY, 1896.

On a careful superficial examination no flaws could be detected, excepting in the case of No. 3 rail, which appeared to have been rolled from a red-short ingot, as it was very rough and "scrappy." No. 1 appeared to have been worn on the head the least of the four rails. The following tests were applied:—(1) They were each tested by the falling weight, which was applied to the head of the rails. (2) Portions of the rails, after cutting into several lengths, were tested by the falling weight, which was applied to the flange, the heads being turned down: (*a*) in their natural state; (*b*) after annealing; (*c*) after filing off 0·02 inch from the top of the head. (3) Vertical longitudinal sections from the centre of the top of each rail were examined with the microscope, after careful polishing and etching. (4) Slices of various thicknesses from the heads were sawn off and tested by bending. (5) Drillings from each rail were chemically examined. (6) Full sections were prepared, and were compared with the original template to ascertain the amount of the steel which had been removed by wear.

No. 1 RAIL.

Marked "No. 1, 1889."

Falling-weight test—

Weight of ball = 1 ton.
Distance between bearing = 3 feet 6 inches.

In natural state on head of rail—

1st	blow of weight	falling	20	feet	gave	$1\frac{1}{16}$	deflection.
2nd	,,	,,	20	,,	,,	$3\frac{1}{8}$	,,
3rd	,,	,,	20	,,	,,	$4\frac{3}{8}$	,,

(*a*) In natural state on flange of rail—

1st	blow of weight	falling	20	feet	broke it.
2nd	,,	,,	10	,,	,,
3rd	,,	,,	5	,,	,,

(*b*) After annealing, on flange of rail—

1st	blow of weight	falling	5	feet	gave	$\frac{7}{8}$	deflection.
2nd	,,	,,	10	,,	,,	$2\frac{7}{16}$	,,
3rd	,,	,,	20	,,	,,	$5\frac{7}{8}$	,,

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(c) In natural state on flange (after removing by filing 0·02 inch of steel from the head of the rail)— Sir Douglas Fox.

1st blow of weight falling 5 feet gave $\frac{3}{4}$ deflection.
2nd „ „ „ 10 „ „ $1\frac{15}{16}$ „
3rd „ „ „ 20 „ broke it at a flaw in the head.

Microscopic Examination No. 1.

A vertical longitudinal section from the highest part of the rail-head was carefully polished, and after etching with dilute nitric acid, was examined under the microscope, which indicated a hardened skin 0·005 inch in thickness.

Bending Tests.

On longitudinal horizontal slices of the steel being taken from the head, No. 1, or uppermost layer, $\frac{1}{100}$ inch, bent to an angle of about 90° and then broke. A thicker piece, $\frac{2}{10}$ inch, broke at about one-third that angle. The thin top layer was most elastic and could be bent to a considerable angle without permanent distortion. No. 2, or second layer, $\frac{8}{100}$ inch from the top, bent close.

The following was the chemical analysis of No. 1:—

	Per cent.
Carbon	0·350
Manganese	0·978
Silicon	0·242
Sulphur	0·055
Phosphorus	0·066
Arsenic	0·043

No. 1.

The proportion of steel worn from the centre of the head was determined by comparing a section of the worn rail with the original template—a horizontal layer about 0·031 inch in thickness.

No. 2 Rail.

Marked "No. 2, 1889."

Falling-weight test—

Weight of ball = 1 ton.
Distance between bearing = 3 feet 6 inches.

In natural state on head of rail—

1st blow of weight falling 20 feet gave $2\frac{3}{16}$ deflection.
2nd „ „ „ 20 „ „ $5\frac{1}{16}$ „
3rd „ „ „ 20 „ „ $6\frac{5}{8}$ „
4th „ „ „ 20 „ „ $8\frac{1}{2}$ „

This rail broke with the fourth blow at the bearing.

(a) In natural state on flange of rail—

1st blow of weight falling 10 feet gave $1\frac{7}{8}$ deflection.
2nd „ „ „ 10 „ „ $3\frac{5}{16}$ „
3rd „ „ „ 20 „ broke it.

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Sir Douglas Fox.

(*b*) After annealing, on flange of rail—

1st blow of weight falling 5 feet gave $1\frac{1}{8}$ deflection.
2nd „ „ „ 20 „ „ 5 „

In natural state on flange (after removing by filing 0·02 inch of steel from the head of the rail)—

1st blow of weight falling 5 feet gave $\frac{7}{8}$ deflection.
2nd „ „ „ 10 „ „ $2\frac{9}{16}$ „
3rd „ „ „ 30 „ „ $5\frac{3}{8}$ „

Microscopic Examination.

A polished and etched vertical longitudinal section from the centre of the top of the head, showed that a hard and altered skin on the head was absent, or so small as not to be detected.

Bending Tests, No. 2.

On longitudinal horizontal slices of the steel being taken from the head, No. 1, or uppermost layer, $\frac{1}{100}$ inch in thickness, bent close without breaking. A layer, $\frac{3}{10}$ inch thick, bent and broke at an angle of about 110°. No. 2 layer, representing steel from 0·02 inch to 0·03 inch from the surface, bent close; and Nos. 3, 4, 5 and 6 all bent close without breaking.

The chemical analysis of No. 2 was as follows:—

	Per cent.
Carbon	0·380
Manganese	0·766
Silicon	0·103
Sulphur	0·090
Phosphorus	0·053
Arsenic	0·013

The proportion of steel worn from the centre of the head, determined by comparing a section of the worn rail with the original template, was a horizontal layer about 0·035 inch in thickness.

No. 3 Rail.

Marked "No. 3, 1889."

Falling-weight test—

Weight of ball = 1 ton.
Distance between bearing = 3 feet 6 inches.

In natural state on head of rail—

1st blow of weight falling 10 feet gave $1\frac{1}{8}$ deflection.
2nd „ „ „ 15 „ „ $2\frac{5}{8}$ „
3rd „ „ „ 20 „ „ $4\frac{7}{8}$ „
4th „ „ „ 20 „ „ $5\frac{3}{4}$ „

(*a*) In natural state on flange of rail—

1st blow of weight falling 10 feet broke it.
2nd „ „ „ 5 „ „

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(*b*) After annealing, on flange of rail—

1st blow of weight falling 10 feet gave $1\frac{1}{16}$ deflection.
2nd „ „ „ 20 „ „ $4\frac{3}{4}$ „

(*c*) In natural state on flange (after removing by filing 0·02 inch of steel from the head of the rail)—

1st blow of weight falling 5 feet gave $\frac{13}{16}$ deflection.
2nd „ „ „ 10 „ „ $2\frac{3}{8}$ „
3rd „ „ „ 20 „ „ $5\frac{1}{2}$ „

Microscopic Examination, No. 3.

A polished etched vertical longitudinal section from the centre of the top of the head, on examination under the microscope, revealed the presence of a hardened skin 0·004 inch in thickness.

Bending Tests, No. 3.

Of the longitudinal horizontal slices cut from the head, No. 1, or uppermost layer, 0·015 inch in thickness, bent and broke at an angle of about 95°. A second piece, 0·30 inch, broke at an angle of about 85°. No. 2 layer, 0·03 inch below the surface, bent over close; and Nos. 3 and 4 layers bent over close.

The chemical analysis, No. 3, was:—

	Per cent.
Carbon	0·410
Manganese	1·066
Silicon	0·070
Sulphur	0·180
Phosphorus	0·067
Arsenic	0·047

The proportion of steel worn from the centre of the head, determined by comparing a section of the worn rail with the original template, was a horizontal layer about 0·090 inch in thickness.

No. 4 Rail.

Marked "No. 4, 1889."

Falling-weight test—

Weight of ball = 1 ton.
Distance between bearings = 3 feet 6 inches.

In natural state on head of rail—

1st blow of weight falling 20 feet gave $2\frac{5}{16}$ deflection.
2nd „ „ „ 20 „ „ $4\frac{1}{2}$ „

The second blow, after giving $4\frac{1}{2}$ inches deflection, caused the rail to break at the bearings where the rail bent over, causing tension in the head.

(*a*) In natural state on flange of rail—

1st blow of weight falling 10 feet broke it.

(*b*) After annealing, on flange of rail—

1st blow of weight falling 5 feet gave $1\frac{1}{16}$ deflection.
2nd „ „ „ 20 „ „ $4\frac{7}{8}$ „

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Sir Douglas Fox.

(c) In natural state on flange (after removing by filing 0·02 inch of steel from the head of the rail)—

1st	blow of weight	falling	5	feet	gave	$\frac{1}{8}$ deflection.
2nd	"	"	10	"	"	$2\frac{1}{8}$ "
3rd	"	"	20	"	"	$5\frac{5}{16}$ "

Microscopic Examination, No. 4.

A polished etched longitudinal vertical section from the centre of the top of the head, on microscopic examination, revealed the presence of a hardened skin 0·006 inch in thickness.

Bending Tests, No. 4.

Of the longitudinal horizontal slices cut from the head, No. 1, or surface layer, $\frac{3}{100}$ inch in thickness, bent and broke at an angle of about 90°. Another piece from the surface was cut out after filing off 0·0024 inch of the steel from the top. This broke at an angle of nearly 180°. A third piece from the surface was tested after filing away 0·007 inch of the steel from the top. This bent over and was pressed close without breaking. No. 2 layer, 0·03 inch below the surface, bent over flat without breaking.

The chemical analysis of No. 4 was:—

	Per cent.
Carbon	0·415
Manganese	0·819
Silicon	0·057
Sulphur	0·066
Phosphorus	0·057
Arsenic	0·043

The proportion of steel worn from the centre of the head, determined by comparing a section of the worn rail with the original template, was a horizontal layer about 0·100 inch in thickness.

General Conclusions.

It is quite evident from the falling-weight tests on the heads of these rails that they are of first-rate quality. No. 1 rail is much harder than the others, due to the large quantity of silicon (0·24 per cent.) present; but for all that, as the carbon and phosphorus are low, it is not brittle, and judging from the slight amount of steel removed by wear (if we may assume that all the four rails have had the same weight over them) it would appear that it will have the longest life. On applying the falling weight to the flange (where fortunately it is not applied on the track) a very small shock is sufficient to cause rupture, and it is evident from the various tests made that the weakness is not due to any mechanical destruction of the steel in the head of the rail, for annealing restores its good qualities, but is caused by a physical alteration of the surface skin of the rail not exceeding $\frac{5}{1000}$ inch in thickness. Judging from the microscopic structure, and elasticity of the strips cut from the surface of the head, it is my opinion that the same change has been produced as is brought about by drawing steel through a wortle plate. In this process the crystal grains are elongated, and then the steel loses practically all its power to elongate under tension and it becomes highly elastic. The elongation of drawn wire is not more than 1 per cent. If this is

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the condition of the skin on the head of this rail, it is clear how it is that when the surface is put in strong tension it speedily reaches its limit of elongation and then breaks, and the crack thus started instantly traverses the whole section and the rail breaks. It is truly astonishing that a skin or layer only $\frac{5}{1000}$ inch should produce such weakness. When rails are worn to any great extent there must necessarily be danger of fracture, for the longer the rail is in use and the heavier the traffic the greater the liability for the head to be thrown into tension by the sinking of a sleeper or the loosening of a fish-plate. In many cases which have come under my notice, the heads of old worn steel rails have not only had the surface physically altered but have had a multitude of fine hair-like cracks, most of them very shallow, but in the case of the Great Northern rail (referred to early in Mr. Kirkaldy's Paper) penetrating to a depth of $\frac{1}{8}$ inch. Most of the cracks in this rail did not sink much below the physically altered area or skin. This hammer-hardened skin had a thickness of from $\frac{1}{100}$ to $\frac{2}{100}$ inch. No. 2 rail is peculiar in this, that the hard skin is practically absent and as a consequence it stood a fairly good falling-weight test when the ball was dropped on the flange. Whether or not this was due to a peculiarity in the steel itself, or was caused by the removal of the altered skin by rusting, or by having lighter traffic passed over it, it is impossible to say. It is interesting to note that a microscopic examination alone of a minute section of the rail-head enables us to see whether or not there is an absence of the hard surface skin, and to decide if it has developed brittleness. No. 3 rail has the same hard surface skin as No. 1, and is easily broken on putting the head into sudden tension. The good property is restored by annealing, showing the absence of disintegration. The "scrappy" rough surface of the rail is accounted for by the high percentage of sulphur which undoubtedly caused the steel to be redshort. Although this rail has good resisting properties to shock, and is for all practical purposes a good rail, it should not have been sent out by the manufacturer with such a rough torn surface. No. 4 rail is good in all respects, and its chemical composition approaches most closely to what is considered ideal, but for all that there has been developed a molecular altered surface skin $\frac{8}{100}$ inch in thickness. This skin is restored to a normal condition on annealing. It would not appear that a pure steel is less liable to develop a hard surface than one of less purity, and I am not surprised at this, for every variety of steel is hardened by wire-drawing and has its power to elongate removed. It must be clear that there will be more or less of the hard skin removed by oxidation when laid on the track, and this, if the traffic is not heavy or great, may balance the development of the hard area; in other words, the hard skin may be rusted off as fast as it is formed. It is possible also that when the rails are laid in sandy districts, even if the traffic is heavy, the grinding away of the hardened or altered surface skin may keep pace with its development.

Sir Douglas Fox.

In a letter he had also received from Mr. J. E. Stead it was stated that:—

In a piece of a broken loco-tire I have cut up and examined microscopically, the structure showed clear evidence of crushing and flow of metal round the tire or to a slight distance from its original position. The external layers travel the greatest distance, the result being that inclined layers of ferrite and pearlite appear. When a section is cut out and is broken by attempting to bend it, it fractures readily and the line taken by the break is along or between the crushed particles of ferrite and pearlite.

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Mr. Gates. Mr. W. H. GATES remarked that if the deflection-curve of a rail, supported at the chairs, and loaded with two locomotive wheels at an average distance apart, were plotted, it was manifest that the rail-head was, as part of a continuous girder, during the greater part of its existence continually in tension. This was abundantly proved by the examination of the broken rails which had come under his notice, where, when the load was in its worst position, viz., one driving axle on the rail-joint—the weakest part of the rail—and the next axle about three sleepers away, the part of the rail-head in greatest tension was some 4 feet 6 inches from the joint, and in the majority of the broken rails he had known the fractures were between 4 feet and 5 feet from the end. A peculiarity of the fractures might be noticed. In all the broken surfaces an incipient flaw was shown in the head of the rail, and the fractures all commenced at the top and worked downwards. The incipient flaw was not normal to the horizontal axis of the rail, but was curved, and there was a projecting portion at what might be called the upper skin of the rail, sometimes projecting forwards and sometimes backwards. As a rule the projection was forwards when the rail was subject to brake action, and backwards when subject to tractive action. This pointed to the conclusion that the steel in the rail might be considered as a fluid or partial fluid mass; and the head of the rail under the weight of the traffic was drawn backwards by the tractive effort of the locomotive, or carried forward by the retarding action of the brakes, as well as being pressed outward towards the side. Another action which took place, although infinitesimal, must also be taken into account, viz., the loaded wheel formed a hollow in the head of the rail, and in its motion raised a hump in front of it, and this action, combined with the dragging due to tractive or brake force, in course of time must effect a change in the longitudinal arrangement of the steel crystals or fibrous structure, destroying whatever cohesion these atoms attained in the process of rolling. This destruction reached such a point in certain rails as to show visible transverse cracks in the upper surface, and once these incipient flaws were started the analogy to a plate of glass with a scratch in it was evident. The tension in the head of the rail showed at the place where it was greatest by a resulting fracture. The expression "wire drawing" to a certain extent represented the action of the traffic, but in addition there was a "cold rolling" process, and as was proved in other operations, few metals would stand much working cold, but must be frequently annealed, and by the annealing presumably the disturbance of the crystalline

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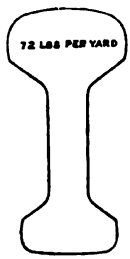
structure was removed and the metal restored to a normal condition. Metallurgists, in considering the best quality of steel for rails, should be guided by the work the steel had to do. He did not offer any opinion as to what was the best, except that a soft steel suffered much more distortion in the form of the head than a hard one. Among Sir W. Roberts-Austen's interesting illustrations some might be noticed that indicated a different arrangement of the components of the steel in a worn rail to that in a new one; and this might be the result of the action he had described, although it was not easy to account for the particles taking to themselves new positions in the internal structure of the steel. Mr. Gates.

Mr. T. E. M. MARSH had investigated the change in the composition or otherwise in certain steel rails that had been in use under heavy traffic for a period of 17 years; it having been found that one, after removal from the line, was brittle and easily broken up though no previous weakness or excessive wear had been apparent. Pieces of the broken rail and other rails of the same make and age, and subjected to similar conditions of wear, were examined and compared with original section, shown in the sketch, and records of manufacture. The rails having been manufactured under his supervision, tests and details at the time of manufacture could be referred to. The results of this investigation and the substance of his report on the subject are as follows, viz.:— Mr. Marsh.



SAMPLE No. 1. (The brittle rail above referred to.)

No perceptible reduction from the original section except the head surface worn down by traffic.

	Inch.
Head worn down	0·20
Head-width not altered	..
Web reduced	0·00
Foot-width reduced	0·05

SAMPLE No. 2. Taken out of the Line for purposes of Comparison.

	Inch.
Head worn down	0·20
Head-width reduced	0·06
Web reduced	0·15
Foot-width reduced	0·20
Foot-thickness reduced	0·15

SAMPLE No. 3. Taken out of the Line for purposes of Comparison.

Practically the same as No. 2.

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Mr. Marsh.

SAMPLE No. 4. Taken out of the Line for purposes of Comparison.

	Inch.
Head worn down	0·15
Head-width reduced	0·05
Web reduced	0·06
Foot-width reduced	0·06

TENSILE TEST.

Pieces cut from the heads of two of the samples gave the following results:—

Area . 0·438 inch before being loaded.
„ . 0·271 inch after loading with progressive loads from 5 to 15 tons.

The breaking strain being rather over 30 tons per square inch of original section.

SAMPLE No. 4.

Area . 0·452 inch before being loaded.
„ . 0·331 inch after loading with progressive loads from 1 to 16 tons.

The breaking strain being about 36 tons per square inch of section.

No satisfactory tensile test was obtained of No. 1 (the sample of a very brittle rail)—it being evidently hard to machine, and incipient flaws were apparent in the pieces broken out of the different parts of the rail.

CHEMICAL ANALYSIS OF SAMPLES WERE MADE AT THE MANUFACTURER'S LABORATORY, WITH THE FOLLOWING RESULT:—

———	Sample No. 1.	Sample No. 2.	Sample No. 4.
C. Carbon	0·475	0·375	0·410
Silicon	0·069	0·047	0·055
Sulphur	0·041	0·072	0·060
Phosphorus	0·058	0·082	0·057
Manganese	0·870	0·680	0·950

The surface alteration due to the wear or waste by traffic was alike in each case; the waste due to other causes was apparent in Samples Nos. 2, 3, and 4, but not so much in No. 1. The cause of this latter waste would probably be attributable to circumstances of the surrounding atmosphere, nature of ballast and other conditions of the metal affected by oxidation. As to brittleness and any change having taken place in the composition of the metal, these are important points for further inquiry. Unquestionably the metal of Sample No. 1 was hard, and must originally have been so, and whatever might be the differences in chemical composition the fractures of the different rails which had been subjected to similar traffic wear clearly showed a difference in

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respect of crystalline composition and nature of the hard and soft rails. The tests also for tensile strain appeared to show that no such great change had taken place in the composition of the latter. Hardness alleged to be caused by long use, the action of rolling loads and vibration causing change. To whatever extent this took place it could hardly be accepted to account for the differences apparent in these samples or for the mysterious behaviour of rails of ample strength and weight in their normal condition for doing their work satisfactorily. But the primary sources of weakness to resist fracture would be in the original material. Any hardening due to these causes might naturally affect more seriously the harder and closer grained metal by vibrations set up tending to disrupture where incipient cracks or cleavages existed. The primary causes of weakness or brittleness would therefore be such as the manufacturers and their chemist should devote their attention to overcome—more effectually than hitherto in the processes of steel-making for rails as now ordinarily practised. The quality of the metal was now more regular than formerly when these rails were made, but latent defects in the ingot metal existed, and these had an important bearing on the question of brittleness and supposed change of composition; cells, bubbles, and cavities, formed by gases in the composition of the metal, were more or less present in the ingots, and where they occurred metallic cohesion of the surrounding crystalline particles was imperfect, and being extended in rolling these became initial points for cleavage, and though not perceptible at first might in course of time, under some conditions of fatigue and vibration, develop into fractures, somewhat as was the case of invisible cracks in glass or the effect of cleavage produced by the diamond. The fractures obtained from these samples clearly indicated in some cases the existence of such initiatory cracks. The bad effects of incipient cracks or disruption of crystalline particles were clearly demonstrated in the early experience of the manufacture and use of Bessemer steel rails, and led to the requirement for fish-joint holes to be wholly drilled. Experiments then made by himself and others clearly demonstrated the weakening effects caused by punching, whether the holes were wholly or partially punched and enlarged by a clean cutter to remove the surrounding metal. In all cases the weakening was apparent as being initiatory points of cleavage.

Mr. Marsh.

Professor A. MARTENS remarked that since the microscopical structure of the same rail presented different appearances according as the specimen was taken from the flange or from the web, in making comparative microscopic investigations of rails of

Prof. Martens.

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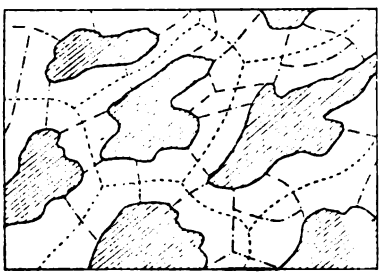
Prof. Martens

different quality the structure for different types of profiles should be compared.[1] The term "size of grain" did not always convey the same definite idea, and the mode of estimating the size of grain was not invariable. In irons poor in carbon there was no difficulty in determining what was to be regarded as a separate grain. Etching with a 1 : 5 solution of nitric acid clearly revealed the boundaries of the grains and made it easy to determine the average size. With other kinds of iron, for example rail steel in which both ferrite and pearlite were found, the determination was more difficult. In the appended sketch the shaded areas diagrammatically represented pearlite, the remaining areas ferrite. For determining what was to be regarded as the average size of grain the following methods might be used: (*a*) the total area of the pearlite islands in a field of vision of definite area might be divided by the number of the islands; (*b*) a surface bounded by the dotted lines might be regarded as a grain, and the average area might be determined; (*c*) the ferrite surfaces alone might be considered, and the grains shown up by a suitable etching material, for example, cupric ammonium chloride; as in the dash-dotted line. It was only the size of grain as determined by method (*c*) that could be compared directly with that determined by etching with dilute nitric acid irons poor in pearlite. The photographs reproduced in Plate 4 showed how it was possible to reveal the grains of ferrite in steels containing considerable portions of pearlite by etching with cupric ammonium chloride,[2] as was shown by E. Heyn, assistant of Professor Martens. Figs. 32, Plate 4, was taken from the middle of the flange of a rail; the polished specimen was treated with iodine solution. The magnification was 365 diameters. The pearlite was shown diagrammatically, coloured black and numbered. Figs. 33 showed the same specimen, but subjected to 15 minutes' etching with a 1 : 12 solution of cupric ammonium chloride. The pearlite was raised above



[1] "Temperature of Rolling Steel Rails, and its Influence on the Strength and Microscopic Structure," A. Martens, Mittheilungen aus den koniglichen technischen Versuchsanstalten zu Berlin, 1896, part ii.

[2] E. Heyn, "Microscopic Investigations on Deeply Etched Iron," Mittheilungen aus den k. technischen Versuchsanstalten zu Berlin, 1898, part vi.

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the ferrite. The pearlite was also shown coloured black; and the grains of ferrite were separated and numbered. Some of the ferrite grains (*a*, *b*, *c*, *d*, *e*,) were dense black, but were easily distinguished from pearlite by their deeper position and their different structure. A comparison between the diagrams showed that the shapes of the pearlite surfaces were somewhat altered, the explanation being that the two sections were really distinct parallel ones, several thousandths of a millimetre apart. The identification of the separate grains of ferrite was easy, on account of the different shape and position of the "etch-figures" on the neighbouring grains. These etch-figures on no account proved that the grains of ferrite were to be considered as aggregates of smaller crystals, but they were merely due to the etching. Every homogeneous crystal showed etch-figures after being etched with a suitable material, both on its surface and on any plane section; the figures were different according as the surfaces were crystallographically similar or dissimilar. These etch-figures were to a certain extent dependent on the symmetry of the crystal, as well as on the etching material. Prof. Martens.

Mr. C. P. SANDBERG observed that in nearly all countries the Governments had established public testing-machines for the materials employed in construction, and in 1897 an international conference was held at Stockholm for testing of materials in the interest of public safety, where Germany especially was represented, and England was conspicuous by her absence. In England the Government had done nothing in this direction, probably owing to this want being to a great extent satisfied by the testing works of Messrs. David Kirkaldy and Son. This showed well enough the merit of the work done by them. Nevertheless he could not agree with their method of testing so far as rails were concerned, nor with the conclusions drawn from their results. All material should be tested as nearly as possible in the same way in which it would be treated in practice, and railway materials, particularly rails, were principally subject to concussion and abrasion. As long as the relationship between the resistance to concussion and tensile strength was unknown, except comparatively by the elongation and the reduction of area, conclusions could not be drawn from the results of tensile or bending tests only for material exposed in practice to concussion or impact, such as rails, and this the Author had done. The effect of wear upon steel rails should not be treated separately from the safety of rails, and here the value of the tup test in conjunction with the chemical composition was shown, both of which the Mr. Sandberg.

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Mr. Sandberg. Author seemed to have discarded altogether in favour of the tensile and dead-load tests. For his own reports on the testing of rail steel he used first the tup test with deflection, then tensile tests with the tons per square inch and elongation, and also chemical tests, all samples being taken by his own inspectors. It was noteworthy that the tons per square inch very nearly coincided with the percentage of carbon. A safe rail was required of sufficient hardness to resist abrasion and crushing, or flow of metal, and, considering the large quantities now being made and inspected daily, these qualities could be best and most promptly ascertained by the tup test on a rail-end from each cast, as well as by analysis for carbon, and thus comparing the carbon with the deflection obtained at the tup test. These were inexpensive and quick tests, and would not hinder the manufacture. The tensile tests, requiring preparation of pieces, were both slow and costly; they, as well as bending tests and microscopical researches, were of great interest, particularly to ascertain the causes of failure of material, but were not applicable in daily rail-inspection. It was to be regretted that the piece of rail referred to early in the Paper was not long enough to be tested by the tup test. He had tested rails broken in service and had found them breaking for a 2-foot or 3-foot blow of a 1-ton ball, while the ordinary test was 20 feet, just showing how the material deteriorated under wear, and very likely this deterioration was due to the transverse flaws detected by the microscope. That these flaws developed more with soft steel was due to the soft steel bending more; but there was the danger of going too far in hardness, which caused the rails to fly in many pieces instead of breaking in one spot only.[1]

The Author's observations and conclusions on the rail-head being in tension over the chairs, and the cracks developing chiefly over these, further strengthened his disapproval of base-plates for flange rails. As a proof, the comparison of the results for the last three years showed that Germany had twenty-two times as many rail-fractures as England, and eighteen times as many as Sweden. The causes of this were probably that the rails in Germany were too light, being only 68 lbs. per yard, laid on base-plates, and that the rails were mostly made of basic steel, which was now adopted in all German railworks except one. It was noteworthy that in Germany, where so many rail-fractures occurred, engineers relied more on tensile tests than on the tup test, the latter being gener-

[1] "The Danger of Using too hard Steel Rails," Journal of the Iron and Steel Institute, vol. liv. p. 76.

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Mr. Sandberg.

ally much less severe than in England, which was another proof against tensile tests being regarded as a criterion for the safety of rails. To show how dangerous it was to draw conclusions from a few experiments, as the Author proposed, he could, from extensive experience in comparing chemical composition with rail-fractures, state that the composition of the Author's ideal rail would be a most dangerous one, and was in fact very much like the German composition of steel rails, which gave the above results in the rail-fracture statistics, and he should certainly warn English railways against adopting this composition. This showed how dangerous it was to draw conclusions from tensile tests of what the rail composition should be for good results, at least for safety. It was well known that such a composition would wear very well, and he had even had good tup-test results from such a composition, but the brittleness was developed by cold hammering of the wheels, so that they gradually broke in large numbers. Those that did not break would certainly show excellent wearing results, but they did not tell the story of the others which broke. He had therefore come to the conclusion that no standard composition of rail steel could be given to suit every country; in fact, no universal chemical composition for steel rails should exist, because so many other conditions were acting in different countries and the circumstances are never identical. As to the Author's desire for standard sections, he had designed series of such for flange rails, both in 1878 and in 1894, and of the former many millions of tons had been made, and those of 1894 were fast being adopted, to the advantage of producers and consumers alike. Since rail-steel had become so cheap, it was true economy for maintenance as well as safety to use heavier rails of medium hardness, and in designing heavier sections of flange rails of 100 lbs. per yard and more, and writing in favour of them, he had never intended to change the English type of road, which was the strongest, but to brush up the Continental roads laid with too light rails on base-plates. As for joints, he had obtained a line of continuous stiffness, both with supported and suspended joints, principally by means of larger bearing surfaces between the rail and the fishplate. He agreed that hard and tough rails would resist wear better, and check the development of the transverse cracks more, than soft rails. But there was the danger of going beyond the limit of safety, particularly as hard rails broke into many pieces and caused accidents, whereas the soft rails generally broke in one place only. To ensure safety he preferred a strong section and rail steel of medium hardness, taking all the components into consideration, and guard-

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Mr. Sandberg. ing above all against high phosphorus, with a tup test severe enough to allow a margin of safety to cover the irregularity in production, and not to be led astray by aiming at the greatest wearing resistance obtained by harder steel which might fly and cause accidents. Although he had inspected more rails than any man, he had, by being guided by the above principles, never had any serious complaints of fractures or of accidents caused thereby; and as to the wearing results, these had been highly satisfactory.

RAIL-FRACTURES IN GERMANY COMPARED WITH SWEDEN AND ENGLAND.

Railways.	Length in Kilometres of Single Line.	Total Rail-fractures.			Fractures per Kilometre.			Accidents from Fractures.		
		1894.	1895.	1896.	1894.	1895.	1896.	1894.	1895.	1896.
German	60,000	8,422	8,372	8,672	0·14	0·14	0·14	2	4	7
Swedish State	3,640	17	30	35	0·0046	0·0082	0·0096	0	0	0
English Railways	48,000	Average per year 300			Average 0·0062			0	1	0

Mr. Stead. Mr. J. E. STEAD, of Middlesbrough, submitted photographs of the rail referred to early in Mr. Kirkaldy's Paper. Fig. 34, Plate 4, illustrated the surface of the head, natural size; while Figs. 36 and 37 showed it magnified 10 diameters, and Fig. 35 60 diameters. Vertical longitudinal sections, showing the hardened skin and cracks, were also given in Figs. 38 and 39, magnified respectively 10 diameters and 60 diameters. He had studied the conditions which appeared to favour the prolongation of the life of steel rails and prevent the development of cracks and flaws, and without entering into detailed descriptions of the experimental data upon which his conclusions were based, he considered that he had evidence which tended to prove that cracking was rarely developed till the finer grained surface-structure in the heads of the rails had been worn away and the much coarser material below exposed. He had also certain results which showed that fine-grained steel would stand more severe treatment without developing cracks than the same material when of coarser structure. The results were not sufficiently numerous to justify him in concluding that a fine-grained steel rail would never crack on the permanent way, but they certainly pointed in that direction. It was easy to obtain a uniformly fine grain in structural steel containing between 0·31 and 0·6 per cent. of carbon by the

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simple process of reheating to about 750° C., and cooling on the benches afterwards. He believed that all steel structures, such as axle-shafts, tires, rails, &c., would be materially improved in shock-resisting properties by that simple treatment. It was doubtful whether railway companies would ever care to pay for much nickel in steel rails, but he thought it not unlikely that they would specify fine-grained steel, and would not object to the slight nominal increase in cost incurred in making them. Mr. Stead.

Mr. KIRKALDY, in reply to the Correspondence, could not agree that the subject should be treated from the very commencement starting at the pig-iron. It was already very wide, and it would be impracticable nowadays, beginning from the pig, to make rails and then wait 10 years, 15 years, or 20 years, until they reached a good service with a view to then ascertaining which steel had best withstood the conditions of traffic. It was quite a wide enough matter to begin by working backwards, ascertaining the properties of worn rails which, after having already performed long services, yet remained in an undeteriorated condition. He agreed as to the advisability of cutting away more from the "crop" ends of rails so as to avoid using the portion from the top end of the ingot. But as regards the assumption that flaws originally in the rails had been mistaken for, and described as induced flaws, he would merely mention that he was able to differentiate between the two classes, and felt confident that the term he had used signified the real category in which to place them. In Mr. Barker's reference to the rails tested by a manufacturer, which had behaved so well, as no notice was taken of the conditions under which those rails were worn, the value of those tests and the conclusions to be drawn from the results were very much reduced. It was probable that if their full history were known they would serve to strengthen the Author's view that, given favourable conditions of service, rails would wear a very long time and then still be found to remain in good and safe condition. Mr. Barker's illustration of tire steel was a good serviceable one and practically embodied the Author's views; it would be gratifying to see rails of a quality approaching that obtained in tires. He thought the results contained in the report communicated by Sir Douglas Fox, obtained from the falling-weight test upon the rails when "inverted," afforded an illustration of the want of definiteness, or exactitude, of the conclusions to be obtained from the falling-weight test; for instance, the report showed that the first blow of a 1-ton weight falling 20 feet broke the rail, but a drop of 10 feet also broke the rail, and so did a drop of 5 feet; from this it appeared that the 10-feet and 20-feet tests were Mr. Kirkaldy.

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Mr. Kirkaldy redundant or useless. In fact this test illustrated exactly what the Author anticipated would happen where it was attempted to determine the deterioration by means of this test with its want of definiteness. He would aim, supposing he were using the falling-weight test, to find within as narrow limits as possible the amount of drop necessary just to produce fracture. In the case in point, would the rail have withstood a 4-foot drop, or would still less fall have sufficed to break it? Otherwise the report was a highly interesting one. He was gratified also by the interesting comments on the subject contributed by Mr. Gates, with whose views he was in accord. With reference to what the Author had termed an "ideal rail," he had asked the permanent-way engineer to procure a rail which had been found in actual practice to behave exceptionally well, and this was the one selected for him; that it should have withstood 23 years' main-line traffic, shown very slight wear, and still retained practically its original qualities, indicated that it was not an unsafe or dangerous steel. He did not wish to convey the idea that he advocated the use of rails high in phosphorus. The comments of Mr. Stead practically bore out the views already expressed by the Author as to the care which should be bestowed in the direction of suitable heat treatment and handling of the steel throughout the course of manufacture.

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24 January, 1899.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

The discussion upon the Papers, "The Effects of Wear upon Steel Rails" and "On Photo-micrography of Steel Rails," occupied the evening.

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31 January, 1899.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

The discussion upon the Papers, "The Effects of Wear upon Steel Rails" and "On Photo-micrography of Steel Rails," was continued and concluded.

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SECT. II.—OTHER SELECTED PAPERS.

(Paper No. 3144.)

"Some Properties of Cordite."

By the late Sir WILLIAM ANDERSON, K.C.B., D.C.L., F.R.S.,
Vice-President Inst. C.E.

CORDITE[1] is an intimate mixture of 58 per cent. of nitro-glycerine, 37 per cent. of gun-cotton, 5 per cent. of vaseline, and probably a trace of non-volatile impurities associated with the acetone, about 20 per cent. of which is used to facilitate the intimate blending of the nitro-glycerine and gun-cotton.

Nitro-glycerine ($C_3H_5N_3O_9$) is a light yellow oily liquid, having a specific gravity of about 1·6; it is inodorous and has a sweet, pungent, aromatic taste. Contact with it or the inhalation of its vapour is apt to produce violent headache in those who are not accustomed to it, but the effect diminishes by degrees; and men who are constantly employed in connection with it after a time suffer no inconvenience. The constituents of nitro-glycerine are in an unstable condition and capable of re-arrangement. Two molecules, on explosion, are converted into 6 (CO_2) + 5 (H_2O) + NO + N 5, from which it will be seen that there is sufficient oxygen to completely oxidize the hydrogen and carbon, and that consequently no CO is produced. Decomposition takes place spontaneously at about 160° C., and detonation at 257° C., or with great violence from local application of heat or from concussion. So dangerous is the substance that its transport is absolutely forbidden. The manufacture of nitro-glycerine is a service of considerable danger unless carried out with the most scrupulous care, but under proper regulations rigorously enforced it is, on account of the absence of dust, not so dangerous as the manufacture of black or brown powders. The effect of the explosion of even very large quantities is by no means so far-reaching as is popularly supposed. In May, 1894, there was, at Waltham Abbey, an explosion of nearly 1¾ ton (3,700 lbs.) of nitro-glycerine; little or no injury resulted to the town. The radius within which appreciable damage was caused did not exceed 900 yards, while

[1] See also "The Machinery used in the manufacture of Cordite," Minutes of Proceedings, Inst. C.E., vol. cxxxii. p. 69.

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serious injury was only experienced within 95 yards. A considerable quantity of nitro-glycerine, which was in a building immediately adjoining one of the two in which the explosion occurred, was not detonated, debris fell within a radius of 700 yards, and a few windows were broken at a distance of 2½ miles. It will be seen from this example how vain and foolish is the idea of laying towns in ruins and destroying fleets and armies by means of nitro-glycerine or explosives with fantastical names derived from it.

Gun-cotton has been familiar to artillerymen for many years, and that known as Abel's gun-cotton is universally used as a violent explosive for war purposes. Its chemical composition is $C_6H_7O_2N_3O_9$, and on combustion these elements rearrange themselves as follows—$5\ CO_2 + CO + H_7 + N_3$, from which it will be seen that there is not sufficient oxygen to ensure complete combustion of the carbon, and this gives rise to a considerable evolution of CO, a poisonous gas which makes its presence felt, when even in small quantities, by causing nausea and headache. When gelatinized gun-cotton is used alone for the charges of heavy guns, the inconvenience described is considerable. The gun-cotton used in making cordite is precisely the same as the service explosive which has been used for so many years in mines and torpedoes, except that no alkali or disinfectant is added as a preservative to the pure article. At Waltham Abbey the gun-cotton pulp intended to be made into cordite is lightly pressed into the form of cylinders 3 inches in diameter and 4½ inches high, containing 9 ounces of the dry material. These cylinders or disks are dried in stoves fitted with light wooden trays having perforated bottoms, each tray holding forty-eight disks. The trays are placed in racks and subjected for about a week to currents of air heated by steam tubular heaters to 100° F. The drying is continued till the moisture is reduced to about ½ per cent. The manufacture of gun-cotton is a perfectly safe operation up to the point where the moisture is reduced below 10 per cent. in the stoves, but then, on account of the light dust, the formation of which it is impossible altogether to avoid, extreme care in the manipulation has to be observed. Formerly the damp gun-cotton was spread as a loose pulp on the trays, but the quantity of dust formed was so great that the present system of moulding the pulp into cylinders was adopted. No one is allowed to enter the stoves while the drying is in progress, except for the purpose of taking samples. When the material is dry and ready for removal, the stoves are allowed to cool, and then the trays are not moved in any way, but the cylinders are carefully transferred by hand from the trays to

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special boxes. The men employed enter with bare feet or wearing only clean socks, the stoves are carefully swept out after each unloading, and are thoroughly washed after every four stovings. At one time the dry gun-cotton was moved into a special store, but, in order to reduce the risks arising from removal as much as possible, the stoves themselves are now treated as stores till the contents have been gradually removed in accordance with the exigencies of manufacture.

In March, 1893, one of the stoves at Waltham Abbey caught fire spontaneously. The wet charge, consisting of 4,212 lbs. of dry gun-cotton, was inserted on the 24th February, and at 6.30 A.M. on 2nd March the attendant examined the thermometers, which could be read without entering the stove, and found them at about 102° F. The stove was to have been emptied that morning, consequently the material was judged to be perfectly dry; but at 7.25 A.M. a bright flame was seen to shoot into the air accompanied by a loud roar, but by nothing in the nature of an explosion. The light circular wooden building, 30 feet in diameter and 10 feet high to the eaves, situated within a strong circular traverse, had its light roof blown off, the woodwork was set on fire, and the intense heat melted most of the lead and copper work, but the traverse which surrounded the stove within a couple of feet of its walls, and even the doors in the tunnel leading through it, were uninjured; in fact the latter had to be unlocked to admit the firemen. As is usual in such cases, no cause could be assigned for the fire; the probable origin lay in the spontaneous combustion of gun-cotton dust collected on the copper heating-pipes, which, at that time, were inside the stove, so that the dust could settle on them. They were, indeed, protected by lagging of non-conducting materials, but it is difficult to believe that the protection was so complete that dust could not make its way to the bare metal, and although the temperature of this did not exceed 120° F., yet even that would in time cause decomposition of substances much less sensitive than gun-cotton. It is well known that insurance companies will not allow hot-water pipes, the temperature of which is generally below 160° F., to be laid in contact with ordinary woodwork, on account of the risk of spontaneous ignition arising from the slow decomposition or charring of the wood. The hot-air pipes are now arranged outside the stoves, and entrances for the hot air are provided all round by means of branches entering through the walls.

Although the fire at Waltham Abbey led to no explosion or loss of life, a similar occurrence at Arklow, in October, 1895, had very

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different consequences. There a stove, measuring 20 feet by 14 feet, was charged with only 275 lbs. of dry gun-cotton, and this exploded violently while a man was manipulating it. The man and stove were blown to pieces, and considerable mischief was caused all round the site. In this case the gun-cotton was in the form of a loose flocculent mass, the workmen wore magazine shoes, and the stove was cold; 25 lbs. of damp gun-cotton, which was in a box on the floor, was not exploded, though it was scattered in all directions. The difference of effect in the two cases cited is very curious, and seems to point to the necessity of drying gun-cotton in the form of compact masses capable of retarding the rapidity of burning, and to the adoption of other precautions prevailing at the Government factory.

The dry gun-cotton is placed, in weighed charges, into brass-lined wooden boxes, and taken to the mixing-room, which also contains the finished nitro-glycerine, which is made in lots of about 700 lbs. The vat containing the nitro-glycerine is placed sufficiently high to allow of drawing it off into gutta-percha jugs placed upon a weighing-machine. Earthenware taps are used, the greatest care is exercised to wipe up every drop that may adhere to the pipes or the jugs, and the movements of the men are slow and deliberate. The weighed charge of nitro-glycerine is then poured over the gun-cotton, and carefully mixed with it by the bare hands of the men. It becomes completely absorbed, and the mass, now called "paste," assumes the appearance of light-brown moist sugar, and, curiously, becomes perfectly safe, that is to say, it will not explode when in moderate quantities, though it burns fiercely. In this condition it is quite safe to transport in regulation packages consisting of waterproof india-rubber bags packed into small barrels. The Government factory supplements its own supply of nitro-glycerine by sending wet gun-cotton to several private factories, and receiving it back in the form of "paste," that is, mixed with nitro-glycerine. It was due to this property that the disastrous explosion to which allusion has been made, and which completely wrecked the nitro-glycerine plant at Waltham Abbey, scarcely interfered with the production of cordite.

The "paste" is next placed into kneading machines, together with about 20 per cent. of acetone, and incorporated for 3½ hours, when 5 per cent. of vaseline, or mineral jelly, is added, and the kneading carried on for another 3½ hours. Acetone acts as a solvent both of the nitro-glycerine and the gun-cotton, and on that account promotes the intimate mixture of the two. It is all

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evaporated during the subsequent processes, and forms, therefore, no part of the finished cordite.

The "dough," as it is called, when thoroughly incorporated, is placed into iron or brass cylinders of various sizes, depending on the diameter of the cords to be produced, and pressed by means of closely-fitting pistons, impelled by hydraulic or screw power, through a die or dies arranged in the bottoms of the cylinders. The dies are really nozzles of diameters and lengths which experience has shown to be suitable for producing the size of cord required. With all the care that is taken to keep the manufacture absolutely clean, it is found impossible to prevent dirt getting in, hence the bottoms of the cylinders are fitted with wire-gauze strainers, through which the dough is pressed before it reaches the nozzles. Occasionally slight explosions occur in the cylinders; their origin is obscure, as many thousand charges are dealt with without accident, but a small portion of a charge sometimes ignites and an explosion more or less violent takes place. Sometimes the force is sufficient to destroy the cylinder and otherwise injure the presses; but, in every instance that has occurred only a very small fraction of the charge has ignited, the bulk of it has remained quite unaffected though possibly scattered about the room. The cords vary in diameter between 0·01 inch and 0·65 inch. The former is used for chopping into pistol ammunition, the latter for the new 12-inch wire gun. The cords for filling into small-arm cartridges are wound on reels holding about 1 lb., on which they are stoved at about 100° F. till the material ceases to lose weight. The larger cords are cut into lengths suited for the cartridges into which they are to be made up, and arranged in thin layers on wooden trays, in which they are stoved in the same way as the reels. In order to insure the greatest possible uniformity, the cords, when thoroughly dry, are blended by carefully mixing a large quantity together. The finished blended cords are then packed in boxes holding between 70 lbs. and 100 lbs. each, and every 10,000 lbs. is called a "lot."

Cordite may be squirted into strands of any shape, but the solid cylindrical form has been found most convenient. A small quantity is made into pipes about 1 inch in diameter by 4 inches long to hold the powder priming of cannon cartridges, to which allusion will be made later. Owing to the compact horny nature of cordite it burns only on the surface, the rapidity of combustion depending on the proportion of surface to volume, on the pressure and temperature in the chamber of the gun. So

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remarkably even is the combustion that cord which is sometimes thrown out of guns only partially consumed retains all its original proportions; the cords are shorter and thinner, but they are truly and evenly cylindrical, even when reduced to the substance of a hair. Cordite can be exploded by concussion, but the explosion is confined to the part contused; the fire is not communicated to the free portions on each side. When not confined in a strong chamber it cannot be exploded even by a detonator; it burns with great fierceness, but without any report.

An experiment was made at the Royal Arsenal, Woolwich, of building eight boxes, containing 100 lbs. of cordite each, into a bonfire. As the boxes burned away and exposed the contents or raised them to the temperature of ignition they flared off one after another, and in most cases the lids of the boxes were not blown off, but merely forced open enough to allow the gases to escape. In order to ascertain the degree of danger to be apprehended in drying cordite, a stove 19 feet 6 inches by 12 feet 6 inches, capable of holding 2,500 lbs. laid out on wooden trays, was built. The walls were of 14-inch brickwork, the roof was of slate; there was a small window in each gable, and a door in one side. The stove was kept at a temperature of 100° for 9 days, and the contents were then set on fire. A vast body of flame was seen to shoot up, the roof was lifted off and deposited, almost uninjured, beside the house, the gable windows were unbroken, and the door was intact and had to be unlocked to admit the firemen to extinguish the burning woodwork.

It does not follow from these experiments that an explosion would not result if several hundred tons of cordite, stored in a magazine, were to catch fire, but it indicates the safety from small explosions which are so disastrous with black powder. If sub-divided sufficiently and packed lightly into strong metal cases it will detonate with great violence, and on that account the boxes in which cordite is stored are made as light as possible, consistent with strength. Experiments also made by firing at the limbers of field-guns show that no explosion of cordite charges carried in them is to be apprehended. Notwithstanding these advantages there has been no relaxation in favour of cordite of the rules which apply to explosives.

The ballistic power of cordite is very nearly four times as great as that of black powder; thus 1 lb. of cordite fired in the 3-inch 12-pounder field-gun produces the same effect as 4 lbs. of selected pebble-powder which used to be the service charge. The cause of this superiority is two-fold. In the first place, only 43 per cent.

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of black powder is operative, that is, produces gas; the remaining 57 per cent. is composed of inert matter, which not only does not add to the propelling power of the gases, but absorbs some portion of their energy in having to be heated and propelled itself. Thus, in the field-gun, which carries a shot of 12½ lbs., of the 4 lbs. of powder burnt a little over 2¼ lbs. are inert, and might as well form part of the shot, so that virtually 1¾ lb. of gases expels 14¾ lbs. of projectile and inert matter. On the other hand, the products of the explosion of cordite are nearly all gaseous and effective. One gram of pebble-powder yields 276 cubic centimetres of gas, while the same weight of cordite gives 664 cubic centimetres, supposing, in both cases, the water produced to be in the liquid state, but, as the 276 cubic centimetres of powder gases weigh only 0·43 gram, it follows that 1 gram of the gas-producing part of the pebble-powder yields 642 cubic centimetres of gas, and is therefore nearly as efficient as the cordite, were it not handicapped by the inert matter associated with it. In the second place, the combustion of 1 gram of pebble-powder yields 714 gram-degrees of heat, while 1 gram of cordite produces 1,225 gram-degrees, which are all expended in heating only efficient gaseous matter, while in the pebble it has also to heat the inert portion; hence the temperature of the gases evolved by the combustion of cordite is much higher, and their tension, at the same density of charge, is much increased. The superior propelling power of cordite, it will thus be seen, is the result of the greater specific volume of gases evolved and their much higher temperature.

Solid cordite has a specific gravity of 1·56, and its volume is therefore 17·77 cubic inches to the lb., and if fired at that density would produce a pressure of more than 120 tons per square inch, whereas the greatest pressure that can be attained with black powder is 43 tons per square inch. Under these circumstances it is imperative to make the gravimetric density of the charge, or the number of cubic inches of chamber capacity to the lb. of explosive sufficiently large to render excessive pressure impossible. Cordite made up into bundles measures about 25 cubic inches to the lb., so that a chamber filled with cords might still yield 112 tons pressure. In the magazine rifle the density is 41 cubic inches to the lb., which might give 68 tons pressure; but in cannon the spacing is now limited, when practicable, to 80 cubic inches to the lb., which cannot give a higher pressure than 30 tons. The pressures named are based on the supposition that no heat is lost in warming the gun and projectile, and that the shot has not begun

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to move before the combustion has been completed. The gun, however, robs the gases of a good deal of heat, the rate of cooling varying roughly inversely as the calibre, and the diameter of the cords is so proportioned that the burning occupies nearly the same time as that taken by the shot in traversing the bore; the maximum possible pressure can therefore never arise, so that densities between 41 and 80 cubic inches to the lb., of suitable sized cordite, are found in practice to be safe. It is apparent, therefore, that the speed with which the shot starts into motion has an important bearing on the pressures in the chamber. If a series of guns of various calibres were constructed with all their dimensions in proportion to the diameter of the respective bores, and in all the shot were impelled by the same initial pressure, then, because the area of the base of the shot, on which the pressure acts, varies as the square of the diameter, while the weight of the shot changes as the cube, it follows that the impelling or accelerating force per lb. of shot varies inversely as the diameter of the bore. The length of the chase, or the space through which the acceleration takes effect, however, increases as the diameter, and therefore the time in which the muzzle velocity is attained is increased in the same proportion, and the velocity is consequently obtained with smaller relative pressures per lb.

This statement will be rendered clearer if the 3-inch field-gun is compared with the 12-inch wire gun. The initial working pressure generally aimed at is 16 tons per square inch; hence the pressure on the base of the 3-inch shot, which weighs 12½ lbs., will be 112 tons, or 9 tons per 1 lb. of shot. In the 12-inch gun the pressure against the base is 1,808 tons, and as the shot weighs 850 lbs., the pressure per 1 lb. is only 2·1 tons, therefore the speed at which the larger shot will start into motion will be about a quarter of that of the smaller shot; and hence, if cordite of a diameter suitable for the small gun were used, the high proportion of surface to volume would cause gas to be evolved at an excessive rate compared with the rate of enlargement of the chamber due to the motion of the shot, and the result would be high pressure. It is hence apparent why it is so important to select the diameter of cord suited to the nature of the gun, and in practice very minute alterations in diameter are found to produce corresponding changes in ballistics. The cords for the 3-inch or 12-pounder field-gun are 0·05 inch diameter, and for the 12-inch gun 0·5 inch, or ten times as great.

When the capacity of the chamber is very great, over 100 cubic inches to the lb., as commonly happens when cordite is adapted to

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the guns made for black powder without any increase to ballistics, then greater latitude may be allowed in the diameter of cords, because the large initial volume of the chamber will prevent the pressure rising beyond 24 tons per square inch, however rapid the burning may be.

Cordite in bundles occupies approximately the same volume as black powder; but because it is four times as efficient, a chamber of one quarter the capacity needed for black powder would hold it, but as about three and a quarter times this volume of air spacing is desirable, the chamber may be about three-quarters of that required for powder to give the same ballistics. The chamber, however, is not nearly filled by the cordite; the bundles of it therefore may be made so small in diameter as to require no greater opening to pass through than that necessary for the shot, hence the great advantages gained of the breech opening not needing to be larger in diameter than that required for the shot, and the practical benefit may be seen in the 12-inch wire cordite gun, which has a breech-block no larger or heavier than that of the 9·2-inch service gun; and it becomes possible to obtain much higher service energies without making the guns inconveniently heavy and bulky. The new 12-inch naval wire cordite gun (mark VIII) weighs only 46 tons, but it has the same penetrating power as the 13½-inch prism powder 67-ton gun.

Cordite, as regards the ballistics it produces, is sensitive to changes of temperature. This, indeed, does not affect the shooting under service conditions, but is often troublesome to manufacturers who have to work within very narrow limits of velocities and pressures. Thus the cordite used in the 12-inch wire gun has to produce a mean velocity of 2,375 feet per second, with the limits plus or minus of 25 feet only, while the pressures must not exceed 17 tons per square inch. To produce such results extreme care must be taken to make the cords of the correct diameter, as a few thousandths of an inch may throw the pressures and velocities up or down. If proofs have to be taken at temperatures varying much from the normal, namely, 60° F. atmospheric temperature and 80° F. of the charge, corrections founded partly on the behaviour of standard lots and partly on empirical rules have to be adopted. To produce cord of any exact diameter is not an easy task, because the material shrinks much in drying and loses weight also by the evaporation of the acetone, but nevertheless experience and careful manipulation enable fairly uniform results to be arrived at.

Because, with the exception of about 5 per cent. of vaseline, the products of combustion of cordite are all gaseous, it is possible,

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by determining the necessary constants, to calculate by purely theoretical methods, the work done on the projectile. The following assumptions have, however, to be made: (1) that the charge is completely consumed before the projectile starts; (2) that the gases do no work in expanding to fill the chamber; and (3), that while the gases are expanding and doing work on the projectile, they do so adiabatically, *i.e.*, without imparting heat to the walls of the gun. Neither of the assumptions is correct; but the discharge of a gun takes place in so small a fraction of a second that the error incurred cannot be great.

The following data have been determined by direct experiment:

Atmospheric pressure	= 2,116 lbs. per square foot.
Volume of products of combustion of 1 lb. of cordite at atmospheric temperature of 32° F. (or 491·16° absolute) . .	= 14·021 cubic feet.
Temperature of explosion	= 6,532·3° F. absolute.
Estimated specific heat of gases at constant volume	= 0·34.
$y = \frac{\text{specific heat at constant pressure}}{\text{specific heat at constant volume}}$.	= 1·23
Heat evolved by exploding 1 lb. of cordite and expanding to atmospheric pressure and 32° F. temperature . .	= 2,054 B.T.U.

With the exception of the specific heat of the gases these data have been determined by direct experiment by Dr. Kellner, Chemist to the War Department. The specific heat of gases at the enormous temperatures and pressures which exist in cannon cannot be arrived at except by means extremely costly, even if then. It has been assumed, therefore, that the value ascertained by Messrs. R. Mallard and Le Chatelier for very hot furnace-gases at atmospheric pressure will hold, and certainly, the closeness of agreement between the calculated muzzle-energies and those obtained by direct measurement in firing guns seem to justify the assumption.

A gun may be regarded as an engine cylinder which gives one stroke of its piston when fired, and therefore the degree of expansion at which it works is an element in the calculations of the power developed. In modern guns the ratio which the volume of the powder chamber bears to the total volume of the bore of the gun is about one-fourth, so that the gases in the gun expand fourfold. In the British service, however, as will be seen by the annexed Table, this figure varies greatly because of the number of guns, originally made to consume black powder, having been converted to cordite guns. There are strenuous advocates for the use of much higher initial pressure than the modest 16 tons or 17 tons

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which forms the limit in use in Her Majesty's Service, but such advocates confine their attention to the possibility of making a safe gun, say, for 30 tons pressure, and quite lose sight of the strength of the walls of shells necessary to stand such pressures, and the consequent reduction of burster. They also ignore the delicate mechanisms of the lock and firing-tube and of the base and nose fuses. It is easy enough to make the gun, but by no means so to make its fittings.

Having determined the proportions of a gun it is only necessary to apply the well-known formula for work done in adiabatic expansion to obtain the energy imparted to the shot, and thence its muzzle-velocity, if this be needed. The following Table gives a list of eight cordite guns in which the calculated and observed muzzle-energies are compared :—

Gun.	Ratio of Volume of Chamber to Total Volume of Bore.	Weight of Cordite Charge.	Muzzle Velocity.	Chamber Pressure.	Muzzle-Energy.		Ratio of Actual to Calculated Muzzle Energy.
					Actual.	Calculated.	
		Lbs.	Foot-Secs.	Tons.	Ft.-Tons.	Ft.-Tons.	
12-inch wire . .	0·2555	167·5	2,361	16·00	32,850	34,585	0·95
9·2-inch wire . .	0·2512	94·5	2,674	17·13	18,860	19,700	0·96
8-inch service . .	0·2487	32·6	2,150	13·81	6,731	6,843	0·98
6-inch service . .	0·2685	14·75	1,960	12·1	2,664	2,948	0·90
6-inch quick-firing .	0·1094	13·25	2,154	12·95	3,217	4,127	0·78
4·7-inch quick-firing	0·0858	5·44	2,150	14·0	1,442	1,797	0·80
4-inch service . .	0·1075	3·56	2,342	14·5	94,512	1,094	0·86
3-inch 12-cwt. . .	0·1874	15·00	2,280	13·6	450·5	543·8	0·83

It will be observed that the efficiency of the guns, *i.e.* the ratio between the calculated and the observed muzzle-energies decreases with the decrease of calibre and increase of expansion. This is to be expected, on account of the relatively high cooling power of the smaller guns.

As regards the stability of cordite under various climatic conditions, extensive experiments have been made, not only at the Arsenal in a hut where it has been kept for a long time under various extremes of temperature and moisture artificially produced, but under natural conditions in the heats of India and the extreme cold of a Canadian and an arctic winter. No difference in ballistics of any practical consequence has been observed, and when chemical tests have indicated some slight change the explosive appears to regain its normal properties when restored to normal conditions.

As stated in the opening paragraph, cordite is but a mechanical

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mixture of the ingredients of which it is composed; hence the nitro-glycerine, which, like all liquids, is volatile, will gradually escape if the cordite be freely exposed, but when kept in the proper manner in service cases no appreciable change has been detected during the time it has, up to the present, been stored. In prolonged cold weather the nitro-glycerine sometimes exudes a little and renders the surface of the cords damp, but it is again absorbed as soon as the material becomes thoroughly warm. Exhaustive experiments have proved that no danger arises from the exudation, and that the ballistics are unaffected.

The action of cordite on the bore of guns is universally supposed to be much more serious than the wear produced by black powder. The Author is at a loss to conjecture how such opinions have arisen. The comparison is not easy to establish, because, as a rule, guns firing cordite have much higher ballistics than those using black powder. For example, the new 12-inch gun imparts to its 850-lb. shot nearly twice the energy which the old service gun communicated to its 714-lb. shot; hence, if the new cordite gun were to wear more quickly it would be no proof that the effect was due to the explosive. The wear produced by cordite is of a totally different character to that resulting from black powder. The latter eats into and scores the surface of the bore in a remarkable manner, obliterating the rifling and allowing very great windage, especially in the upper part of the bore. This is probably due to the mass of inert solid or liquid matter rushing past the shot, and, in so doing, rasping out the steel. In the case of cordite, the surface of the bore seems to be dissolved and washed away by the exceedingly hot gases, the effect being greatest close to the seat of the shot, and dying away in five or six calibres. The washed-out part is comparatively smooth and free from scoring, the rifling is not obliterated, though a good deal levelled down, but the wear is so favourable that, by fitting the shot with special driving bands provided with obturating rings formed like U leathers, the sealing of the bore, the maintenance of the proper initial position of the shot, and its correct rotation are secured. When the surface of the bore of a worn gun is carefully examined, it is seen that the effect of the hot gases evolved both by the black powder and cordite is to produce a network of fine longitudinal and transverse cracks, especially in the vicinity of the chamber. In the smaller natures, the reticulations so produced are very regular, and measure between $\frac{1}{16}$ inch and $\frac{3}{16}$ inch in the side, while in the 11-inch powder-proof gun the meshes vary between $\frac{1}{8}$ inch and 1 inch in the side, but the larger squares are not so well defined

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as the smaller. It would seem as if the frequent and violent compression of the metal caused by the pressure of the powder gases, assisted by the expansion due to rapid heating, probably to about the critical temperature of steel, had the effect of crushing the material, while the sudden release and cooling at the conclusion of the discharge caused a reaction or resilience which produced the cracks. The larger the gun, the deeper the fissures appear to be, and it would seem as if the rush of gas occasionally broke out squares of steel, and afterwards polished the cavities so formed.

The Author had an opportunity of comparing the wear of two 4·7-inch quick-firing guns, one of which had fired 1,039 rounds of black powder, and the other 1,219 rounds of cordite; the velocity in the former gun was 1,781 foot-seconds, and that of the latter 2,189 foot-seconds, and as the energies imparted to the shot vary as the squares of the velocities, it follows that the cordite gun develops 51 per cent. more work than the other, yet the powder gun was deeply scored and eroded, while the other retained its smoothness and even a good deal of the rifling, though the bore near the chamber is considerably enlarged, though not more than that of the powder gun. The Author's belief is that the endurance of cordite guns will be found to be considerably greater than that of those using black powder, in spite of their increased ballistics.

Cordite is unaffected by water, whether fresh or salt. Samples were submerged at Shoeburyness for a considerable time, a portion was then merely dried, another was washed in fresh water and dried, while a third was fired wet. The first two gave normal ballistics; the last showed, as might be expected, a slight falling off due to the evaporation of the water. A barge loaded with cordite was recently accidentally sunk off the Woolwich Arsenal. The cargo lay submerged for a tide; it was then recovered, and the boxes of wet cordite were sent to Waltham, where, in about a month after the accident, the contents were washed, dried, and re-issued to the service after satisfactory proof.

The combustion of cordite yields about 34 per cent. of carbonic oxide gas, and though this is undoubtedly a poisonous substance, no inconvenience whatever has been experienced from its presence. It is also an inflammable gas, and under favourable conditions of wind, cases are not uncommon when, in opening the breech immediately after firing, a tongue of flame issues to the rear. The drill is specially arranged to meet this circumstance, so that no inconvenience arises in practice, neither is there any danger to the next charge in breech-loading guns, because by the time the shot is rammed home all flame has disappeared, and even if the

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cartridge which follows the shot were to catch fire, it would not explode like black powder, but simply burn away unless there had been time to close the breech, which would be very unlikely.

One of the difficulties which beset the introduction of cordite was the ignition of the charge. It is most important, especially for naval guns, that there should be no hang-fires, that is, that the charge shall go off the moment the tube is fired. Cordite by itself cannot be ignited by the ordinary tubes, and a priming of some kind is necessary. Dry gun-cotton acts very well, but is objectionable on account of its dangerous nature. Fine-grain powder, however, answers every purpose, and has also the advantage of making a little smoke which, with that produced by the vaseline, helps to lubricate the bore. In ordinary cannon cartridges, with axial ignition, the priming is applied in the form of a pad of red shalloon, filled with about 8 oz. of powder, for the larger natures, and secured to the end of the charge. In quick-firing guns it is of the greatest consequence that there should be no residue from the cartridges left in the bore, as that would interfere with rapid loading; the priming of $1\frac{1}{4}$ oz. is therefore placed in thin shalloon bags inside tubes, made of cordite, built into the cartridge, the whole being contained in the brass quick-firing cases. In small arms, where the cords forming the charge are very fine, only 0·0375 inch diameter, all that is required is a somewhat stronger cap filled with a composition which gives a long flame. In the case of guns having radial vents the priming is placed as a band round the cartridge, so as always to come under the vent, however the charge may be inserted.

All the more important qualities of cordite have now been touched upon, and although it is possible that smokeless powders, composed of gelatinized gun-cotton alone or mixed with various mineral ingredients, may be equally good, there can be no doubt that cordite is, weight for weight, more efficient, and therefore makes up into lighter cartridges. It produces much less of the poisonous carbonic-oxide gas, and, in addition, it is much cheaper.

Like every other new warlike store it has been attacked with considerable virulence, but it is surviving these onslaughts and growing in favour with those who have to use it, and who are responsible for the defence of the country. About seven years' experience has now been obtained with it, and it can be safely asserted that cordite is permanent, safe and trustworthy under all the varied conditions under which it has to be used in the British Empire.

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(Paper No. 3092.)

"Westport Harbour, New Zealand.—Wave-Basin."

By THOMAS HAROLD RAWSON, M. Inst. C.E.

WESTPORT HARBOUR is situated at the mouth of the Buller River, on the west coast of the middle island of New Zealand, and is the most important coal port of that colony. The river discharges into the Tasman Sea, nearly at right angles to the coast line. About 6 miles to the westward of the entrance a natural shelter from the prevailing south-westerly winds is formed by Cape Foulwind and the Steeples, which extend northwards from the coast.

The outside works have been carried out practically as designed by the late Sir John Coode in his report of December 1880, and consist of granite-rubble breakwaters, the outer sides being covered with blocks between 10 tons and 30 tons in weight, the western one being 4,200 feet in length, and built to about 16 feet above high water of spring tides, and the eastern 4,750 feet, with the last 1,100 feet to half-tide level only. The western breakwater has an overlap of 400 feet, and the width at the entrance is 700 feet. These breakwaters were commenced in 1886 and were completed in 1893; they have proved entirely successful, and have fully borne out the designer's anticipations, giving a fixed wide entrance, with an increase in depth of about 10 feet. Where formerly steamers of 200 tons to 300 tons traded with difficulty, and with frequent detentions, the port is now conveniently worked by both steamers and sailing vessels taking out 1,500 tons to 2,000 tons of coal. The rise of neap tides is approximately 5½ feet, and of spring tides 9½ feet, the mean depth on the bar at high water being about 20 feet 6 inches. The internal training-walls now nearly completed have been somewhat modified from Sir John Coode's plan, and are being carried out in accordance with the plans laid down by Mr. Napier Bell, M. Inst. C.E.

In designing these works, Sir J. Coode splayed the breakwaters to provide for wave-basins on both sides, to quote from his report, "For the dissipation of scend or undulation which might enter between the breakwaters during gales." The entrance is open to

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gales from the north-north-west to the north-north-east, but the

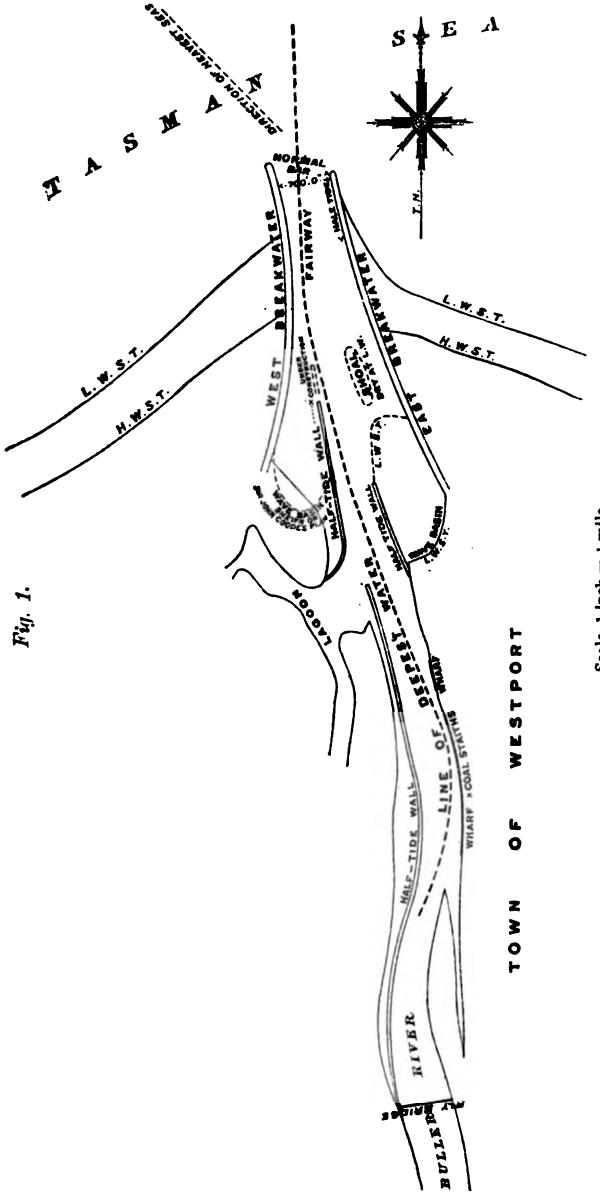

Fig. 1.

Scale, 1 inch = ¼ mile.

WESTPORT HARBOUR, NEW ZEALAND, WAVE-BASIN.

heaviest seas are experienced from the north-west; in exceptional

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cases, occurring perhaps not once in a year, these seas break about 1 mile out, in about 8 fathoms of water, and from thence to the bar is a mass of broken water. On ordinary occasions, however, the break is close to and on the bar; and in what is considered a very heavy sea the waves range between about 10 feet and 12 feet in height. From whatever direction the seas may come, the scend or undulation runs up the entrance to the eastward of the fairway, and breaks in waves of 4 feet to 6 feet in height on the shoal indicated in *Fig. 1*; and then again in somewhat smaller waves in the eastern wave-basin. The break at low water is dissipated on the shoal. On the line of fairway, and about ½ mile above the bar, the undulation is almost dissipated, and under the most unfavourable circumstances, viz., at high water with a heavy sea on the bar, the scend or undulation practically does not reach the wharves or coal staiths, and therefore does not affect the shipping. It also does not extend along the western side of the fairway beyond the above point, viz., about ½ mile from the bar, and therefore there is no break on the river beach at the projected western wave-basin.

The Author for the last 4 years, as engineer to the Westport Harbour Board, has had the carrying out of the internal half-tide walls, extension of wharves, and dredging operations, and his experience has shown that it was not necessary to have provided a wave-basin on the western side, and that the western breakwater might have been run out straight from a point about 1,000 feet higher up the river bank. This would have been advantageous to the fairway, and would have effected a saving in cost, for it would not then have been necessary to have constructed the lower western half-tide training wall—a costly piece of work, owing to the depth of water down the greater part of its length.

The amount already expended on the Westport Harbour Works, including about 12 miles of railway to connect it with the quarries, is about £500,000.

The Paper is accompanied by a drawing from which the Figure in the text has been prepared.

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(Paper No. 3130.)

"Floods in the Brisbane River; and a System of Predicting their Heights and Times."

By CYRUS JOHN RICHARD WILLIAMS, Assoc. M. Inst. C.E.

THE Brisbane River Valley extends over an area of about 5,200 square miles above Brisbane, and lies generally in a north-west and south-east direction, between latitudes 26° 30′ and 28°. It is bounded on all sides by mountain ranges, varying in height between 1,000 feet and 3,000 feet. The upper half of the valley is formed generally of impervious strata, and the lower or southern half of permeable strata. Throughout most of its devious course of 210 miles the river flows near the eastern side of the valley, so that the majority of its tributaries join it from the west or right side. The only branch of considerable size on the east is the Stanley River, which joins it at a distance of 115 miles above Victoria Bridge in Brisbane, or 135 miles above the mouth. This river rises among high lands near the sea coast, in the neighbourhood of Crohamhurst, and drains an area of 600 square miles, subject, under influences which will be referred to later, to such intense rainfall that it is a question whether, as regards floods, it should not be considered the main river; the usual effect of the extraordinary rainfall in the Crohamhurst district being such that the Stanley River is of equal effect in producing floods in the main river below the junction, with the Upper Brisbane River draining three times the area. The other principal branches are Lockyer Creek, draining an area of 1,160 square miles, and the Bremer River, draining 780 square miles, and joining the main river 97 miles and 49 miles above the mouth respectively.

Tropical disturbances generally travel south and west, from the direction of the New Hebrides Islands, and strike the Queensland coast, recurving to the south-east in approximate parallelism with the Brisbane and Stanley Rivers. They shed their rainfall in such a way that as the floods come down the river they are being continually supplemented, and under such influence the

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conditions necessary to produce a flood at Brisbane usually obtain. These conditions are, an average of 2½ inches of rain over the whole valley, when the latter is in a saturated condition, or about 5 inches when such is not the case, occurring within a period of 4 days, and distributed in such a manner that the flood-waves in the main branches and the river shall approximately coincide at the different junctions.

The Brisbane River is tidal for a length of 53 miles, and navigable for vessels of 4,000 tons as far as Brisbane. The low- and high-water lines are practically level to Victoria Bridge, and the high-water line is level up to the Bremer junction. The tidal range at the mouth of the river and at Brisbane is between 3 feet and 8 feet, and at the Bremer junction between 1 foot and 3 feet.

The dates and heights above low-water datum at Brisbane of floods in the Brisbane River since 1840 are given in the following Table:—

TABLE I.

	Feet.	Inches.
14 January, 1841	30	7
1845	Height not ascertained	
16 April, 1852	,,	,,
19 May, 1857	13	8
16 February, 1863	13	10
20 March, 1864	15	4
21 April, 1867	Height not recorded	
10 March, 1870	12	5
18 June, 1873	11	9
1 March, 1875	11	6
16 October, 1879	11	0
23 January, 1887	15	4
20 July, 1889	15	3
13 March, 1890	20	5
5 February, 1893	30	4
19 February, 1893	29	6
12 June, 1893	14	10
14 February, 1896	9	6
29 February, 1896	9	0
13 January, 1898	19	5
10 March, 1898	13	8

The information relating to floods prior to 1887 is not very precise, and that part of the Table has been compiled from old newspapers and notes by wharf-owners and others. The standard of reference was usually "High-water"—a somewhat vague point as no standard high-water datum had been fixed. The height given for the "great flood" of 1841 is even more open to question. Captain Wickham, one of the first police magistrates of Queensland, is reported to have said that the water was 20 feet deep at

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a certain point in the city, and by referring to the original survey of Brisbane, with levels, the height in the Table is the least that can be deduced. It will be seen from the Table that, although January, February, and March, comprising the "wet season" in this sub-tropical country, are the months during which floods may usually be expected, there is risk of flooding between October and July.

Table II. gives the observed times, and intervals of passage from the preceding gauge, of the flood-waves of 1893, 1896 and 1898, together with the velocities of the wave-crests and the greatest recorded heights above summer level at the different gauges. It shows great irregularity in the time intervals of the different floods and in the speeds of the wave of the same flood between the different gauges, which are not to be accounted for by the gradients nor the hydraulic mean depths. The explanation of the irregularities is that, owing to the influx of fresh volumes of water between the gauges, the observed crest at the lower gauge does not necessarily correspond with that at the upper one. If the influx of water takes place just in front of the crest as it passes down, the new crest formed by the combination will be in advance of the position which would have been reached by the original one in the same time; the interval of passage will appear short and the speed excessive, and *vice versâ*.

It would require a much larger number of observations than are available to eliminate this source of irregularity by "averaging;" and another complexity is also introduced in that there are decided indications that large flood-waves travel down the river more slowly than small waves. This apparent anomaly requires explanation, and the following occurs to the Author. The speed of the flood-wave crest is sensibly less than that of the water itself, because the highest water is being constantly drawn off to fill low-lying lands, and a new crest formed behind the point where the old one would have reached. As the high flood-crests are more subject to this drain than the low, their apparent crests are delayed more, and so much more as to counteract the effect of the greater hydraulic mean depth of the stream.

More observations are, however, required to establish a rule for the variation of the speeds in relation to the heights of the flood-waves. It is to be expected that when these observations are available, it will be found that the velocity of the wave-crest increases to a certain height, while the river is practically within its banks, and that above that height the velocity falls off.

The catchment of the Brisbane River and the position of the

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TABLE II.—VELOCITIES AND HEIGHTS OF THE FLOOD-WAVES OF 1893, 1896 AND 1898.

—	Time of Passage of Wave-Crest.					Elapsed Time from Next Preceding Gauge.						Velocity of Wave-Crest in Miles per Hour.						Greatest Recorded Heights above Summer Level.					
	January, 1893.	February, 1896.	February, 1896.	January, 1898.	March, 1898.	1893.	14 February, 1896.	29 February, 1896.	January, 1898.	March, 1898.	Average.	1893.	14 February, 1896.	29 February, 1896.	January, 1898.	March, 1898.	Average.	1893.	14 February, 1896.	29 February, 1896.	January, 1898.	March, 1898.	
						Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.							Ft. Ins.	Ft.in.	Ft.in.	Ft.in.	Ft. ins.	
Caboonbah	9.30 p.m., 3rd.	10.20 a.m., 12th.	7.15 p.m., 27th.	Mid-night, 10th.	5.30 a.m., 8th.	16·5	13·5	..	6·0	..	..	2·4	4·0	..	3·3	..	..	74 2	51 0	44 0	58 6	54 3	
Lowood	5 a.m., 4th.	10 p.m., 12th.	7.30 a.m., 28th.	3 p.m., 11th.	8.30 p.m., 8th.	7·5	9·5	12·3	15·0	15·0	11·8	5·3	4·2	3·3	3·6	2·7	3·8	86 7	52 4	45 0	68 3	58 10	
Ipswich pumping station	Noon, 4th.	6.45 a.m., 13th.	2 p.m., 28th.	7 a.m., 12th.	5 a.m., 9th.	7·0	8·8	6·5	16·0	8·5	9·3	5·7	2·9	3·8	2·6	2·9	3·5	94 10	48 4	41 0	66 0	54 10	
Goodna	4.30 a.m., 5th.	2 p.m., 13th.	10.30 p.m., 28th.	3 p.m., 12th.	10 a.m., 9th.	16·5	7·3	8·5	8·0	5·0	9·0	1·3	2·9	2·6	2·1	4·4	2·7	71 1	30 3	24 6	49 0	36 9	
Brisbane	7 p.m., 5th.	10 p.m., 13th.	5 a.m., 29th.	Mid-night, 12th.	5 p.m., 9th.	14·5	8·0	7·5	7·5	7·0	8·9	1·8	3·2	3·3	2·7	3·7	2·9	30 4	9 6	9 0	19 4	13 8	
Woodford	5 a.m., 3rd.	9 p.m., 11th.	..	6 p.m., 10th.	..	..	..	..	..	..	..	..	..	..	..	..	..	38 6	23 9	16 6	33 9	29 0	
Cressbrook	..	2.30 a.m., 12th.	3 p.m., 27th.	9 p.m., 10th.	..	..	..	..	..	..	..	..	..	..	..	..	..	50 2½	39 3	..	42 0	41 0	
Gatton	..	Noon, 12th.	9 p.m., 27th.	10 p.m., 10th.	..	..	..	..	..	..	..	..	..	..	..	..	..	53 7	11 9	16 0	24 0	..	

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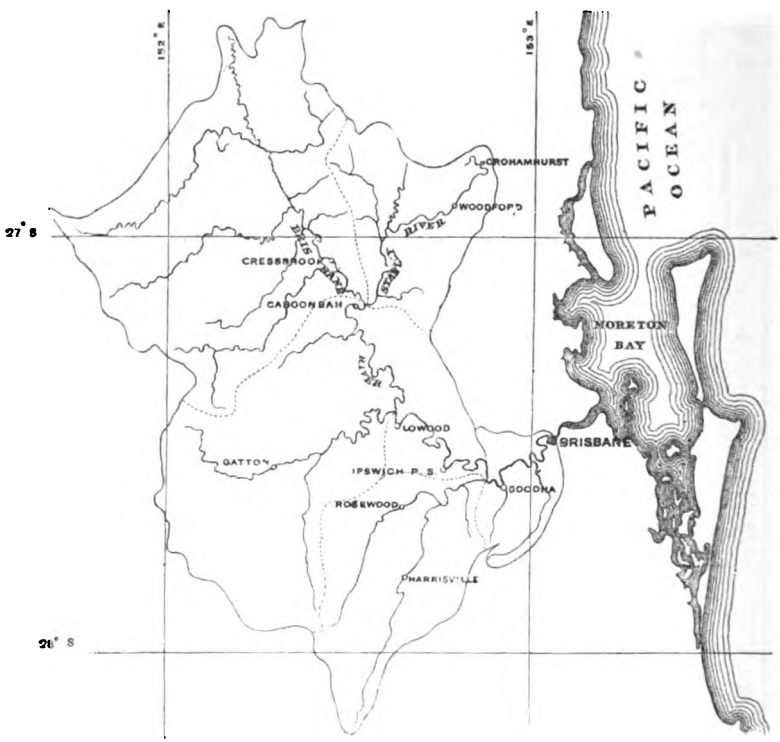
valley in relation to the sea coast are shown in *Fig. 1*; and the heights to which the various floods, of which records are available, rose at the gauges, are given in *Fig. 2*. Lines joining these points show the average gradients of the imaginary lines swept by the wave-crests.

A "hydrograph" or diagram of flood-wave profiles of the flood of January, 1898, is shown in *Fig. 3*. The horizontal lengths

Fig. 1.



CATCHMENT AREA OF THE BRISBANE RIVER, WITH THE POSITIONS OF THE GAUGES.

represent intervals of time, and the heights represent the rise above summer level of the river at the gauges. Such diagrams show graphically the heights, character and sequence of the rises at the different gauges, and form the basis for analyzing the waves at the different points, tracing the influences of the component tributaries; and so, from the rises as reported, the "stages" of the river are predicted.

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A comparison between the rainfall over the catchment and the flood discharge of the Brisbane River corresponding with the floods of 1893 and 1898, is given in the following Table:—

TABLE III.

Flood.	Rainfall.	Flood Discharge.	Rainfall Discharged.
	Cubic Feet.	Cubic Feet.	Per Cent.
5 February, 1893 . . .	181,209,000,000	115,974,000,000	64
19 February, 1893 . . .	118,094,000,000	100,379,000,000	85
13 January, 1898 . . .	61,369,000,000	56,000,000,000	91

The exceptionally high percentage of flow-off in January, 1898,

Fig. 2.

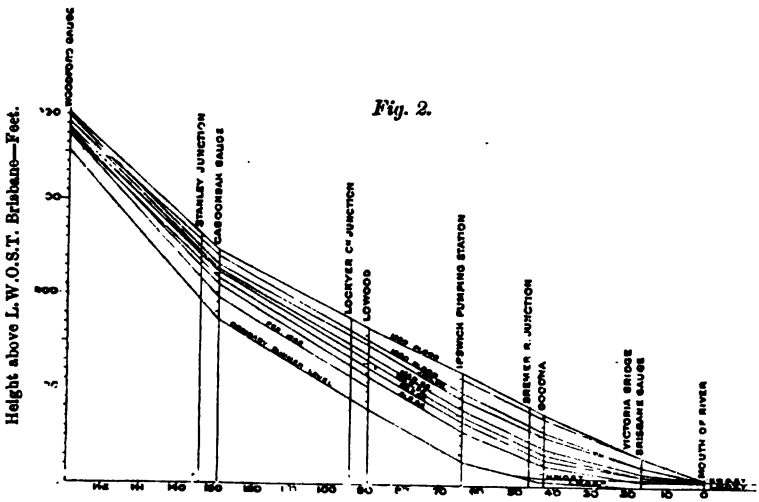

DIAGRAM SHOWING THE HEIGHTS TO WHICH FLOODS OF WHICH RECORDS ARE AVAILABLE ROSE AT THE VARIOUS GAUGES.

is due to the saturated condition of the catchment-area, as rain had been falling with sufficient intensity to keep the river in a state of "fresh" from some time before Christmas to the 3rd January, when the heavy rain, which was the immediate cause of the flood, set in. These results are not put forward as more than a rough approximation, because the rain-gauge stations are widely scattered, and the discharges computed from surface velocities only, observations being made of the speeds of logs and other débris passing

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fixed points, the coefficient for reduction to average velocity being 0·75.

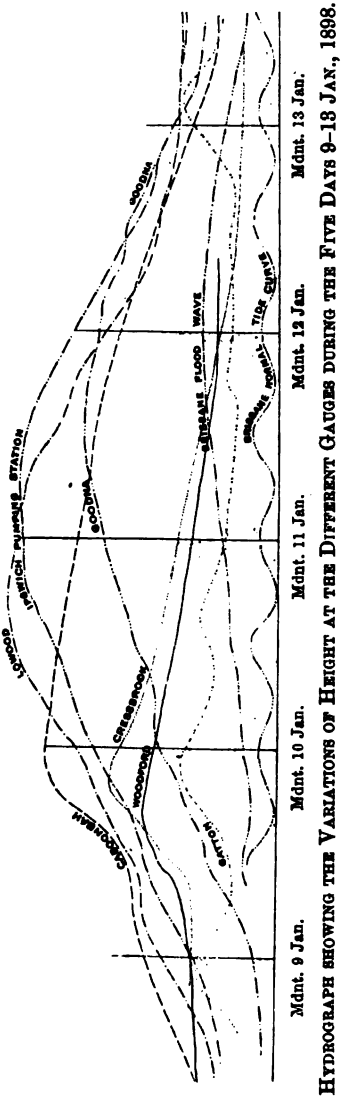

Fig. 3.

HYDROGRAPH SHOWING THE VARIATIONS OF HEIGHT AT THE DIFFERENT GAUGES DURING THE FIVE DAYS 9–13 JAN., 1898.

Owing to the losses from floods of which no warnings were given, it has become part of the duties of the Water-Supply Department, under the charge of Mr. J. B. Henderson, M. Inst. C.E., Government Hydraulic Engineer, and in his absence, of the Author, to collect data, erect flood-gauges, ensure communication between them and headquarters, receive the telegraphed gauge-readings, and issue warning notices predicting the probable heights and times of floods. It is well understood that the number of observing stations is inadequate, but only those in communication with police-stations and telegraph or telephone lines have yet been adopted, and financial reasons have prevented the installation of special observing stations.

System of Predicting :—In any river the power of a branch or tributary to produce flooding in the main stream varies with the drainage-area, the intensity of the rainfall, and the rapidity with which that rainfall is discharged, which in turn depends on the permeability of the foundation strata and the inclination of the water-courses. An immense amount of information, involving observations extending over many years, is required to determine how long after a rainfall on any catchment

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a flood-wave corresponding to that fall may be expected in the branch of the river draining that catchment; and when it is remembered that each wave in each branch is a combination of those in the creeks flowing into it, it will be seen that the problem is extremely intricate. Also the rainfall is usually only recorded at a few scattered stations, and does not necessarily give the true average fall, so that another element of uncertainty is introduced. For these reasons, the observed rainfall alone is not a reliable basis for determining the river rises. Readings of flood-gauges at suitable points in the main stream and its branches, however, give an accurate solution of the problem of the combination of the various elements indicated. Those gauges in the river should be placed immediately below the junctions of all main branches, and in the branches the upper one should be placed high enough to catch as many as possible of the head creeks, and the lower one as low as possible but clear of backwater from the river. The gauges should be connected by spirit-levelling, a cross section of each branch and of the river should be taken at each gauge, as well as the gradient of the stream when normal and when in flood. Observations should be made of the velocity of the stream when in flood at different heights, rising and falling, and gauge readings taken of a few floods from which the average velocities of the waves may be derived. With these data curves of discharge at different heights rising and falling can be plotted for each gauge to one scale, the vertical heights representing heights on the gauge and the horizontals representing units of water passing. The sum of the units of water passing the gauges on the component branches, corrected for time of passage by measuring back on a diagram of wave-profiles, or in some other way, will give the units of water passing the gauge below the junction, and the height on the gauge corresponding with that quantity is the predicted height of the flood-wave, which prediction will, in accuracy, vary as the accuracy of the data. This system extended down the river, will, if the data are accurate and complete, give an exact prediction of the height and time well in advance of the flood.

Actual System in Use.—In the absence of the complete information described, some of which would require years of observation to obtain and verify, it was necessary to devise a system by means of which approximate predictions, based on whatever observations were available, could be made. The system devised by the Author is founded on a set of curves of discharge in which the vertical heights represent heights on the

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gauges, and the horizontal lengths represent units of water passing the gauges, corresponding to those heights. The curve for the lowest station, Brisbane, is derived from observations taken at the height of the 1893 and 1898 floods, during the low flood of March, 1898, and the "freshes" of 1896. By observing continuously, through a series of tides, curves for high and low water are drawn, which enable the effect of the state of the tide to be taken into account in predicting the flood-heights. The curves for the other gauges have been drawn on the assumption, as a first approximation, that the maximum flow past each gauge in any flood varies as the catchment-area above the gauge and the intensity of the rainfall, and that the lower parts of the curve are parabolas. They would be such if the sides of the valley sloped in straight lines to a point in the bed, and the departure is not great when the bed of the stream has sensible width, as in the ordinary streams in a country where the rainfall is heavy, but confined to one season of the year. The curves when drawn are then adjusted by "trial and error" until they approximately fulfil all the observed conditions of previous floods.

The curves used are for Woodford, Cressbrook, Caboonbah, Lowood, Ipswich pumping-station, Goodna, and Brisbane. The scale for the Woodford and Gatton curves is increased as if all the water for the Stanley River passed Woodford and all that of Lockyer creek passed Gatton, as it has been observed that the rainfall is fairly consistent over those valleys. The gauge at Ipswich pumping-station is not of great importance, as there is no well-defined influx of water between it and Lowood, but it is a useful check, in case of delay or failure of reports from Lowood or Goodna. Curves for the other gauges have not yet been constructed, because the records of readings on them are not sufficiently extended, so that it is necessary to use the rainfall averages to complete the computations.

The method of working the system is as follows:—The observers watch the gauges, and during rainy weather telegraph the readings, at 9 A.M. each day, until the water reaches certain heights (defined in the instructions), when they report at shorter intervals, even hourly when the water is at a dangerous height. These readings are plotted on the "hydrographs" immediately they are received, and as soon as the maximum has been reached at Woodford and Cressbrook, an estimate is made of the height and time at Caboonbah, and by this time the water at Gatton has usually reached its maximum. The time from Cressbrook to Caboonbah is about 5 hours, and as from its nature the Cressbrook wave has more

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influence in forming a distinct crest at Caboonbah than the Woodford one the time at Caboonbah is assumed to be 5 hours after Cressbrook. By scaling on 5 hours to Caboonbah, and back 12 hours to Woodford, and adding the units, the estimated height and profile of the Caboonbah wave can be made up, transferring heights into units before adding, and reconverting units into heights after adding. If the rainfall on the Cressbrook catchment has been equal to the average of the Upper Brisbane river catchment, one-fifth must be added to the Cressbrook units, or proportionately less if the rainfall is less. In the same way the flood-wave in Lockyer Creek, reaching Lowood in about the same time as the Cressbrook wave, is combined, giving the estimated height at Lowood.

The average flood-rainfall over the whole basin and over the branch catchments having been taken out:—If the rainfall over the country between Lowood and Ipswich pumping-station is approximately equal to the average over the basin, the Lowood units are increased one-tenth for the increase of area and the Ipswich pumping-station estimate is made up, or proportionately as in the case of Cressbrook Creek. In the same way one-fourth is added to the Lowood units for increase of area above Goodna, and one-twentieth to the Goodna units for increase of area between Goodna and Brisbane. A prediction for Brisbane is thus taken out as soon as the two primary waves at Woodford and Cressbrook have been recorded, or 38 hours in advance of the flood-crest.

The Appendix shows the working of the system as applied to different floods, with the heights as computed by the Author's system compared with the observed heights on the different gauges.

The Paper is accompanied by three drawings, from which the Figures in the text have been prepared.

[APPENDIX.

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APPENDIX.

FLOOD OF 5 FEBRUARY, 1893.

	Feet.	Ins.	Units.	Heights by Author's System. Feet.	Ins.	Observed Heights of Floods. Feet.	Ins.
Cressbrook rise	50	2½	= 8·40				
„ add one-fifth	..		= 1·68				
Woodford rise	38	6	= 4·60				
Caboonbah	..		14·68 =	73	0	74	2
Gatton rise was 53 feet 7 inches = to 8·6 units, but the crest was 12 hours too late for coincidence. It is assumed that one-half the maximum volume was passing	..		4·30				
Lowood	..		18·98 =	90	0	87	0
Rainfall up to average between Lowood and Ipswich pumping-station, so add one-tenth	..		1·89				
Ipswich pumping-station.	..		20·87 =	95	0	94	10
Rainfall one-half up to average between Lowood and Goodna, so	..		18·98				
add one-eighth to Lowood units	..		2·61				
Goodna	..		23·47 =	71	0	71	0
Rainfall up to average between Goodna and Brisbane, so add one-twentieth	..		1·17				
Brisbane	..		24·64 =	30	0	30	4

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"FRESH" OF 14 JANUARY, 1896.

—	Feet. Ins.	Units.	Heights by Author's System. Feet. Ins.	Observed Heights of Floods. Feet. Ins.
Cressbrook rise	39 0 =	4·80		
„ add one-fifth	..	0·96		
Woodford rise	23 0 =	1·60		
Caboonbah	..	7·36 =	49 0	51 0
Gatton rise	11 0 =	0·40		
Lowood	..	7·76 =	52 0	52 4
Rainfall between Lowood and Goodna was one-half the average, so add one-eighth to Lowood units	..	0·94		
Goodna	..	8·70 =	31 0	30 3
Rainfall between Goodna and Brisbane one-half the average, so add one-fortieth	..	0·21		
Brisbane.	..	8·91 =	9 9	9 6

"FRESH" OF 21 FEBRUARY, 1896.

—	Feet. Ins.	Units.	Heights by Author's System. Feet. Ins.	Observed Heights of Floods. Feet. Ins.
Cressbrook rise	26 0 =	2·50		
„ add one-fifth	..	0·50		
Woodford rise	19 6 =	1·20		
Caboonbah	..	4·20 =	36 6	35 6
Gatton rise	7 0 =	0·20		
Lowood	..	4·40 =	36 0	36 0
No rainfall between Lowood and Goodna.				
Goodna	..	4·40 =	18 0	18 0
No rainfall between Goodna and Brisbane.				
Brisbane.	..	4·40 =	7 0 h.w. 3 6 l.w.	No record.

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"FRESH" OF 29 FEBRUARY, 1896.

—	Feet.	Ins.		Units.	Height by Author's System. Feet.	Ins.	Observed Heights of Floods. Feet.	Ins.
Cressbrook rise	37	0	=	4·30				
„ add one-fifth	..			0·86				
Woodford rise	16	0	=	0·70				
Caboonbah	..			5·86 =	43	0	44	0
Gatton rise	16	0	=	0·80				
Lowood	..			6·66 =	45	0	45	0
No rainfall between Lowood and Goodna.								
Goodna	..			6·66 =	25	0	24	6
No rainfall between Goodna and Brisbane.								
Brisbane	..			6·66 =	8	0	8	0

FLOOD OF JANUARY, 1898.

—	Feet.	Ins.		Units.	Heights by Author's System. Feet.	Ins.	Observed Heights of Floods. Feet.	Ins.
Cressbrook rise	42	0	=	5·50				
„ add one-fifth	..			1·10				
Woodford rise	30	0	=	3·80				
Caboonbah	..			10·40 =	59	0	58	6
Gatton rise	24	0	=	2·00				
Lowood	..			12·40 =	68	0	68	3
Rainfall up to average between Lowood and Ipswich pumping-station, so add one-tenth	..			1·24				
Ipswich pumping-station	..			13·64 =	66	0	66	0
Rainfall 10 per cent. above the average, between Lowood and Goodna, so add (one-fourth + 10 per cent.) to Lowood units	..			12·40				
	..			3·40				
Goodna	..			15·80 =	49	0	49	0
Rainfall 20 per cent. above the average between Goodna and Brisbane	..			0 95				
Brisbane	..			16 75 =	19	6	19	5

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FLOOD OF MARCH, 1898.

	Feet. Ins.	Units.	Heights by Author's System. Feet. Ins.	Observed Heights of Floods. Feet. Ins.
Cressbrook rise	41 0 =	5·20		
„ add one-fifth . . .	..	1·04		
Woodford rise	27 6 =	2·40		
Caboonbah	..	8·64 =	53 9	54 3
Gatton rise	8 6 =	0·30		
Lowood	..	8·94		
Rainfall up to average between Lowood and Ipswich pumping-station, so add one-tenth . .	..	0·89		
Ipswich pumping-station .	..	9·83 =	52 0	54 10
Rainfall up to average between Lowood and Goodna, so add one-fourth to Lowood . . .	..	8·94		
	..	2·47		
Goodna	..	11·41 =	37 6	36 9
Rainfall up to average between Goodna and Brisbane, so add one-twentieth	..	0·57		
Brisbane.	..	11·98 =	13 9	13 8

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(Paper No. 3147.)

"The Brussels International Congress on Navigation of 1898; the Bruges Ship-Canal; and New Works at Ostend and Antwerp."

By Leveson Francis Vernon-Harcourt, M.A., M. Inst. C.E.

The Seventh International Congress on Navigation, held at Brussels during the last week of July, 1898, was attended by the Author as the delegate of the Institution. The work of the Congress was distributed amongst five sections, by which subjects relating to (1) canalized rivers, (2) inland navigation canals, (3) tidal rivers and ship canals, (4) seaports, and (5) tolls and dues, were separately considered. Eighteen questions were drawn up by the organizing committee for consideration by the Congress, four being allotted to each of the first four sections, and two to the fifth section[1]; and seventy-eight reports were presented on these questions by engineers from Austria, Belgium, France, Germany,

[1] The following is a summary of the questions reported upon and discussed at the Congress:—*1st Section:* (1) Methods of raising existing movable weirs, so as to interfere as little as possible with the navigation; (2) works to prevent the flow of water under the sills of weirs; (3) utilization of the fall of water at weirs for the traction of boats, and the working of locks and weirs; (4) the influence of the form of boats, and the condition of their surface, on their resistance to traction. *2nd Section:* (1) Systems of mechanical traction along canals; (2) advantages of different types of single gates for locks; (3) methods of securing the watertightness of the bed and banks of a canal; (4) the mechanical lifting, from reach to reach, of the water supplying a canal. *3rd Section:* (1) Formulary of the characteristic particulars about a tidal river; (2) methods of calculating tidal volumes in a river; (3) means of consolidating the slopes of ship-canals; (4) the most recent results obtained with different types of large dredgers. *4th Section:* (1) Warehouses and sheds: their arrangements, dimensions, construction, and siding accommodation; (2) relative areas of basins, quays, sidings, and warehouses and sheds, at seaports; (3) free ports: their object, condition of establishment, installations, and dimensions; (4) recent arrangements for single gates or caissons at sea-locks. *5th Section:* (1) Tolls, dues, and local charges, and the method of levying them; (2) unification of the system of measurement for inland canal boats.

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Great Britain, Hungary, the Netherlands, Russia, and the United States. These reports furnished a basis for the separate discussion of the questions at five meetings of the sections to which they respectively belonged; and conclusions on each of the questions allotted to them were agreed upon by each section at the close of the discussion on the subject. These conclusions were then presented severally to the final general meeting of the Congress, by representatives of the five sections, and, after being put to the vote in succession, were formally adopted as the decisions of the Congress.

The above reference to the arrangements and proceedings of the Navigation Congress, together with the list of questions which formed the basis of its deliberations, as given in the note, will suffice to give a general notion of the information collected, and the work carried out by the Congress; whilst full particulars about these subjects can be obtained by consulting the extensive set of reports presented to the Congress, and the records of the proceedings of the sections and the Congress, in the library of the Institution.[1] Under these circumstances, the Author believes that he will best serve the interests of the Institution, in relation to the Brussels Congress, by giving a brief account of the navigation works in progress in Belgium visited by the Congress, together with some reference to proposed extensions.

On the invitation of the Paris Chamber of Commerce, the Brussels Congress decided, at its closing meeting, to hold the next International Navigation Congress in Paris in 1900.

Bruges Ship-Canal.

Bruges was one of the most important centres of commerce in Europe between the thirteenth and fifteenth centuries; but it gradually lost its sea-going trade by the silting-up of the Zwyn, an arm of the sea, Fig. 1, Plate 5. A canal was made from Bruges to Ostend early in the seventeenth century, which was subsequently enlarged; and this canal, which for nearly three centuries has furnished Bruges with its only outlet to the sea, and

[1] A set of these reports, and the Guide-Programme, giving brief accounts, with plans, of the ports and waterways of Belgium, together with copies of the other documents and pamphlets distributed to the members attending the Congress, have been procured by the Author for the library of the Institution; and an account of the proceedings of the Congress and of the sections, which is being prepared by the organizing committee, will in due course be presented to the Institution.

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also serves for the drainage of the district, has at the present time a depth of 14 feet, and an available width of 39½ feet. For many years past proposals have been made to revive the commercial prosperity of Bruges by connecting it with the North Sea by a ship-canal, formed across the 7½ miles of low-lying land separating it from the sea-coast near Heyst, where the conditions of depth and drift are more favourable than elsewhere in the neighbourhood, Fig 1, Plate 5. The schemes have always included the construction of a harbour at the outlet, for protecting the channel between deep water in the sea and the entrance to the canal; and in one of the earlier schemes, the design for the harbour consisted of two converging breakwaters, very similar to Ymuiden Harbour at the North Sea approach to the Amsterdam Ship-Canal.

General Description of Works.—The design, which was finally approved by the Government in 1895 and is now in course of construction, comprises a single breakwater, connected with the shore by an open viaduct to prevent interference with the inshore currents and the consequent progression of the foreshore, and curving round from the north towards the east, so as to protect the entrance to the canal from west round to north-north-east, whilst leaving the approach quite open from the east, Figs. 1, 2, and 3, Plate 5. The wide entrance-channel is guided and protected across the foreshore, between low- and high-water mark, by a low masonry jetty on each side; and this channel, 820 yards long, leads to a sea-lock with an entrance width of 65⅔ feet. This sea-lock provides an available length of 840 feet between its gates; and the upper end of the lock opens into an inner basin, 744 yards long, with five jetties projecting out over its western slope, alongside which vessels will be able to lie, Figs. 2, 8, 9, 13, and 14, Plate 5. The actual canal starts from the inshore end of the inner basin, and runs in a straight southerly line direct to Bruges, at the outskirts of which, after a course of about 6½ miles, it enters the wide north basin of the port of Bruges, Fig. 1, Plate 5. This north basin gives direct access to the east and west basins of unequal length; and the longer west basin will communicate with the Bruges-Ostend canal, by a lock leading out from the southern end of the basin, Fig. 16, Plate 5.

Condition of Sea-coast at the Entrance to the Canal.—The outlying sandbanks which exist in the North Sea, opposite the coasts of France and Belgium, attain their greatest development in front of Dunkirk, and diminish gradually in extent in passing from thence towards the mouth of the Scheldt; and at the same time the slope of the foreshore becomes steeper, and deep water is reached nearer

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the coast. The greatest inshore depths are found close to the mouth of the Scheldt; but the improvement near Heyst is very marked, even as compared with the coast at Blankenberghe, a short distance to the south-west, so that it has been possible to obtain a favourable situation for a harbour not far removed from the nearest point of the coast to Bruges, Fig. 1, Plate 5. The site selected, now known as Zeebrugge, is about 1½ mile to the west of Heyst, where depths of 4 fathoms are found within 500 yards of low-water mark, and from which the Wielingen Channel, the approach channel to the Scheldt, is not far distant, and can be reached by crossing a bank with a minimum depth over it of 20 feet at low water of spring tides, and across which a channel could be readily dredged so as to obtain a depth of 4½ fathoms to 5 fathoms at low tide, Fig. 1, Plate 5. The material drifted along this part of the coast consists mainly of large quantities of very fine silt, readily carried along by the currents, but depositing in sheltered places.

Zeebrugge Harbour.—The harbour forming the approach to the canal is also intended to serve as a port of call for large steamers on their way to other ports, where direct railway connection with the various commercial centres of continental Europe will afford facilities for landing and embarking passengers, and for the despatch and the receiving of cargoes without undue loss of time. The breakwater has, therefore, to provide a sufficient space for a quay, with railway lines, travelling cranes, and sheds, and a quay-wall against which vessels can lie, as well as to shelter the harbour giving access to the canal from the sea, Fig. 4, Plate 5. An approach to the solid curved breakwater is provided by an embankment 761 feet long, extending across the beach from high-water to low-water mark, leading to an open jetty, resting on steel piles placed 16½ feet apart, which connects the embankment with the breakwater, and has a length of 1,007 feet, Fig. 2, Plate 5. The embankment is intended to protect the harbour from the inroad of sand blown by the prevalent westerly winds along the beach; and the open jetty is designed to allow enough of the tidal currents of flood and ebb to pass through the harbour to keep down the deposits of silt which might be expected to take place in a closed harbour on that coast. Owing to the curvature of the jetty, the actual width of open channel left between low-water mark and the breakwater, measured at right angles to the shore, is only 820 feet. The starting point of the jetty is about 930 yards to the west of the centre of the entrance channel of the canal.

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The solid breakwater, starting from the outer end of the open jetty, is designed to have a length of 4,984 feet, making a total length of embankment, jetty, and breakwater, from high-water mark to the extremity of the work, of 6,752 feet, Fig. 2, Plate 5. The structure is curved throughout, with a radius of 59⅔ chains from the shore to nearly half-way along the breakwater, and from thence with a radius of nearly 99½ chains to the end, where the breakwater becomes approximately parallel to the coast, extending out into a depth of 4½ fathoms at a distance of 930 yards from low-water mark. The wide portion of the breakwater, forming a quay, is to extend from the jetty for a length of 3,918 feet, consisting of a concrete-block quay-wall on the harbour side, a concrete-block sea-wall on the sea side, and filling between the two walls; and the width at quay level will be 177 feet, of which 10 feet will be occupied by the protecting parapet of the sea-wall, and the remaining 167 feet will be available for travelling cranes, lines of railway, and sheds, Fig. 4, Plate 5. The outer 1,066 feet of the work are to be built as a simple solid breakwater, solely for protecting the harbour and entrance channel, 29½ feet wide at the base, 21⅓ feet at the middle portion, and 14¾ feet for the parapet wall; and the breakwater will be terminated by a round head, 52½ feet in diameter, with a light on it to mark the entrance. About 270 acres of harbour area will be sheltered by the breakwater from all quarters except the east, from which direction the storms are not severe; and a portion of this area, adjoining the site of the quay-wall and extending about 980 feet out from it, has a depth of from 4½ fathoms to 5 fathoms at low water of spring tides, Figs. 2 and 3, Plate 5.

Concrete Blocks of 3,000 Tons.—The lower portion of the sea-wall of the breakwater is to be formed of huge concrete blocks built up in metal caissons, 82 feet long, 24⅔ feet wide, and varying in height from about 23 feet to 30 feet, according to the depth of the sea-bottom, so that their tops may emerge 3¼ feet above low water of spring tides, and weighing from 2,500 tons to 3,000 tons, Figs. 4, 5, 6, and 7, Plate 5. Somewhat similar blocks, but with a batter on the outer face, are being constructed in a similar manner for the base of the quay-wall of the breakwater, Fig. 4. The caissons for these blocks are being erected in the inner basin, above the lock, which is kept dry, Fig. 2. The caissons have a cutting-edge round the bottom, and are strengthened at the base by a series of lattice girders, and at the sides by triangular lattice stays extending up the whole height of the caisson; and they are being partially filled with concrete over

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the bottom and round the sides, as shown in the illustrations, Figs. 5, 6, and 7, so that while partly finished, and strengthened for their voyage to their ultimate site, they may retain sufficient buoyancy to float with their tops 3¼ feet out of water when immersed. The concrete is composed of 1 part of Portland cement, 2¾ parts of sand, and 4¼ parts of small porphyry stone.

Directly the lock has been finished, and the whole number of caissons, with their inner concrete lining, have been completed, the water will be admitted from the entrance channel, through the lock, into the inner basin; and the floating blocks will then be passed through the lock one by one, in calm weather, and towed to their site by tugs, Fig. 2, Plate 5. When a block has been moored in its exact position, wooden plugs closing holes left in the sides will be removed; and the hollow block, filling with water, will settle down, either on the natural bottom where suitable, or on a foundation where the inequalities of the bed have been levelled by a layer of small rubble stone from Tournai. The filling of the block with concrete will then be completed, with the aid of a Titan crane running on the finished portion of the work, by means of closed skips having a capacity of 6½ cubic yards. The same Titan will subsequently lay the courses of 50-ton concrete blocks, on the top of the large caisson blocks which rise 3¼ feet above low water. These blocks will raise the sea- and quay-walls to 23 feet above low water, and 8⅓ feet above high water of spring tides; and the protecting parapet wall will be raised on the top of the sea-wall with concrete in mass deposited within frames to a height of 19⅔ feet, or about 28 feet above high water, with a thickness of nearly 10 feet for the greater part of its height, Fig. 4. The large foundation blocks of the sea-wall will be protected from being undermined by the scour of the waves rebounding from the wall, by an apron of rubble stone extending 50 feet out from the face of the blocks.

Entrance Channel.—The channel forming the approach to the canal from the harbour has a trumpet-shaped outlet across the beach, bounded on each side by a low mound of stone, pitched on the top and raised slightly above the surface of the beach, Figs. 2 and 13, Plate 5. Timber jetties, following the inside toe of the mound on each side, 6½ feet wide, and carrying a footway raised 23 feet above low water, serve to mark the boundaries of the entrance channel across the beach at high tide, and provide access to the lights at the pier-heads, between which there is an entrance width of 656 feet; and dolphins ranged near the base of the side slopes indicate the limits of the navigable channel, Fig. 13.

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The channel narrows gradually, between its entrance and high-water mark, to its normal width of 164 feet at the bottom and 348 feet at the level of high water of spring tides; and it has been given a depth throughout of 19⅔ feet below low water, and 34½ feet at high water of spring tides, Fig. 13. A berm, 3¼ feet wide, has been formed at the sides of the channel at low-water level, where the slope changes from 3 to 1 below to 2 to 1 above; and the upper slope on each side is pitched throughout from low-water level up to the surface of the ground, 23 feet above low water.

Zeebrugge Sea-Lock.—The average tidal rise of springs at the entrance to the canal is about 14 feet 9 inches; and in order to prevent the tide from running into and out of the canal, which would create currents and alterations in the water-level injurious to the sides of the canal and inconvenient for navigation, a lock is being built at the upper end of the entrance channel for excluding the tide from the canal and basins on the inland side of the lock. This lock has a total length of 925 feet; and it consists of an entrance at each end, 203½ feet long, providing a passage for vessels 65⅔ feet wide between vertical quay-walls, Figs. 2 and 8, Plate 5, and a wider lock chamber between the entrances, 518 feet long, bounded by a battered quay-wall along its western side and a pitched slope along its eastern side, and having a bottom width of 83½ feet and a top width of 128¾ feet, Fig. 9. The entrances at the two ends are alike in arrangement and dimensions, but reversed in position, the caisson chambers and swing-bridge foundations being in both cases on the western side of the lock, and at equal distances from their respective ends, Figs. 2 and 8.

The lock will be closed at each end by a steel caisson running on wheels, which can be drawn into a caisson chamber provided for it at the side of the entrance, when the lock has to be opened, Figs. 8 and 10, Plate 5; and the available length for locking vessels between these caissons is 840 feet. As a shallow trench lined with masonry has been formed in the floor of the lock across each entrance, along which the caisson travels, the remainder of the floors of the entrances with their sills and aprons, and the floor of the lock chamber, have been laid to a uniform level of 18 feet below low water of spring tides, or 1⅔ foot higher than the bed of the entrance channel, Figs. 9 and 10, Plate 5.

Sluiceways have been formed in the side walls, controlled by cylindrical sluice-gates, which will serve for the filling and emptying of the lock chamber; and outlets are so arranged for them that the water flowing through them can be used, when

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required, for scouring the caisson chamber, Figs. 8 and 10. Foundations for a swing-bridge have been provided on the western side of each lock entrance; for one swing-bridge is to carry a road and a single line of railway across the outer entrance, and another will carry a double line of railway across the inner entrance. These swing-bridges will each have a swing portion 83 feet long, and a tail end 52½ feet long.

Rolling Caissons at the Sea-Lock.—The caissons closing the sea-lock, 14¾ feet wide, 41⅔ feet high, and 80½ feet long at the top and 68 feet at the bottom, weigh 200 tons as designed, which, together with 279 tons of ballast, will make a total weight of 479 tons, or 50 tons in excess of the 429 tons of water displaced by the air-chamber, and thus ensure the stability of the caisson when being moved.[1] The power to be applied for drawing the caisson into or out of its chamber has been so proportioned to the resistances to be overcome, that the operation of opening or closing the lock will, it is calculated, be accomplished in 2⅔ minutes. Provision has also been made for working the caisson by hand, so that in the event of a breakdown of the power supplied, three men will be able to put the caisson in place or draw it back in 15 minutes. Each caisson will travel on four pairs of wheels, 3½ feet in diameter, arranged two and two near each extremity, running on rails laid in the recess in the floor, Figs. 10, 11, and 12, Plate 5. Meeting faces have been formed on both sides for the caisson to close against, according as the water-level is the highest on its upper or lower side, leaving a play of 1⅔ foot between the meeting faces and the sides of the caisson, to allow the escape of the water along the sides of the faces when the caisson is being moved. The caissons will accordingly be able to retain a head of water on either side; and therefore each caisson, serving as a flood-tide or ebb-tide gate according to circumstances, will perform the functions of a double pair of ordinary lock-gates pointing in opposite directions, whilst taking up less space in the length of the lock than a single pair of gates with the gate recesses on each side, so that the available length for locking vessels is only 85 feet less than the length of the lock.

The wheels on which the caisson travels and their rails will be accessible for repairs by means of a chamber encircling each set of four wheels, 7½ feet wide and stretching right across the caisson,

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[1] "Portes à un seul vantail de l'écluse maritime du nouveau canal de Bruges." C. Piens, VII^me^ Congrès International de Navigation, Bruxelles 1898, Quatrième Section, 4^me^ Question.

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into which compressed air can be forced, and which will be reached by a shaft, 2½ feet in diameter, provided with an air-lock. A third shaft in each caisson will enable the watertight air-chamber to be inspected and repaired. Five sluiceways formed through the caisson near the bottom, 3¼ feet wide and 2½ feet high, will enable the sills and floor of the lock to be kept clear of sediment, Figs. 11 and 12, Plate 5.

Electrical Installation.—An electric-power station has been set up, in which two engines of 250-HP. drive two dynamos, each furnishing a current of 330 amperes at a pressure of 440 volts, which supplies the power to the various machines employed on the works, such as pumps, cranes, brick-making, and mortar- and concrete-mixing machines, pile-drivers, sawmills, and repairing shops. In the future, the electric power will be employed for working the caissons, swing-bridges, sluice-gates, and capstans at the sea-lock, the travelling cranes on the breakwater of Zeebrugge Harbour, and the machinery of a repairing shop, and also for lighting the harbour, the sea-lock, and the approaches to the port.

Inner Basin at Zeebrugge.—The widened channel intervening between the upper end of the lock and the canal, with its five wooden jetties on its western slope, provides a sheltered basin for the accommodation of vessels in close proximity to the sea, in addition to serving as the approach channel to the canal, Figs. 2 and 14, Plate 5. This basin has a length of 744 yards, a bottom width of 164 feet, a width at the water-level of 316 feet, a depth of 26¼ feet, side slopes of 2 to 1 and 3 to 1, and a quay along the western side, 246 feet wide and raised 11½ feet above the water-level, provided with a road and railway sidings. The bottom of the basin, which is level with the bottom of the canal, is 3¼ feet higher than the sills and floor of the sea-lock. This basin will be filled with water as soon as the sea-lock and the casings of the large blocks, being constructed on the bottom of the basin, are completed.

Ship-Canal to Bruges.—The canal about 6¼ miles long, extending from the inner basin at Zeebrugge to the Port of Bruges, has a depth of 26¼ feet, which can be increased to 28 feet, a width of 72 feet at the bottom and 230 feet at the water-level, side slopes of 3 to 1 from the bottom up to 5 feet below the water-level, where a berm 5 feet wide has been formed, and 2 to 1 slopes above, pitched with stone from 5 feet below up to 5 feet above the water-level, Figs. 1 and 15, Plate 5. The canal excavations, which are full of water, are being carried to their requisite dimensions by two bucket-ladder dredgers, which discharge the

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sand and silt which they remove, mixed with water, through a long shoot on to the land on each side of the canal, to form the embankments bordering the canal.

A swing-bridge, 167 feet long and 15¾ feet wide between the middle of its girders, turning on a central pivot, and carrying a road across the canal about midway along its length, will leave, when open, a clear width of 72 feet for navigation. A ferry also for vehicles is to be established for crossing the canal between this bridge and the Zeebrugge basin.

Port of Bruges.—The accommodation being provided on the north side of Bruges for vessels consists of a wide outer basin, in which vessels will be able to turn round, which connects the canal with the east and west inner basins, parallel to one another and separated by a projecting quay, 394 feet wide, Fig. 16, Plate 5. The east basin is designed to be surrounded by quay-walls having a total length of 2,625 feet, and to have a depth of 26¼ feet, the same as the canal. The west basin, about 1,770 feet long, is encircled by pitched slopes, to be furnished with the necessary jetties, and has a depth of 21⅓ feet; and it will communicate at its inner end with the Bruges-Ostend Canal, and thereby with the inland waterways of the district, by a lock 39⅓ feet wide, having a chamber 320 feet long, and a depth of 13⅓ feet over the upper sill. The lock will open into a widened portion of the Bruges-Ostend Canal, where vessels will have space for turning. Two swing-bridges, across the two ends of the lock, will afford a passage for a railway and a roadway respectively.

The quays adjoining the basins are to be equipped with sheds, sidings, and steam-cranes, for dealing with the traffic of the port.

Cost and Duration of the Works.—The works are being carried out by Messrs. Coiseau and Cousin for the contract sum of £1,545,160. They were commenced about the beginning of 1896; and by the middle of 1898, the expenditure had reached about £440,000, the rate of expenditure averaging at that period about £22,500 per month.[1] The stipulated time for the completion of the works is September, 1902, being seven years after the passing of the decree approving the works. About two-thirds of the funds are provided by the State; the major portion of the remaining third has been subscribed by the town of Bruges; and the rest is furnished by a company formed for working the canal, and the province of West Flanders.

Remarks on the Bruges Ship-Canal Works.—The most novel

[1] "Le Port d'escale, et le Port intérieure de Bruges." Brussels, 1898, p. 35.

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features of these works are the large blocks being constructed for the breakwater, the employment of rolling caissons for the gates of a commercial lock worked by electricity, and the very extensive use of electric power for actuating the machines in operation for the construction of the works.

Large blocks on a somewhat similar principle have, indeed, been adopted for the superstructure of the breakwaters in course of construction for sheltering the approach to the River Nervion giving access to the Port of Bilbao; but these blocks do not exceed 42⅔ feet in length, 23 feet in width, and the same in height, having a weight of about 1,400 tons, so that they are not quite half the size and weight of the largest blocks being constructed at Zeebrugge. The method also determined upon for putting the huge 3000-ton blocks in place for forming the Zeebrugge breakwater is of interest, as furnishing a simple expedient for handling blocks of such a size as might otherwise appear to be unmanageable; whilst the adaptation of these huge blocks for forming a quay-wall constitutes a useful development of the system.

Rolling caissons have been used for closing graving docks, and also instead of ordinary gates at the locks of naval dockyards, in which cases the moving of the caissons is only occasionally required; but it is a new departure to resort to rolling caissons for a lock which will frequently have to be opened and closed near the time of high water, if the new port attracts the traffic anticipated. Such an arrangement is only permissible in view of the rapidity and facility with which it is calculated that these caissons will be drawn into or out of their chambers by electric power. The advantages of these caissons are, that the lock chamber can be made longer in proportion to the length of the lock than with gates, that the sills have not to be raised above the floor of the lock, and that in this instance the caissons will serve the purposes of flood-tide and ebb-tide gates, in place of two pairs of reverse lock-gates at each end of the lock. Caissons are often adapted to serve as bridges, when in place, for heavy loads; but, in this case, it has been deemed expedient to provide movable bridges over the lock distinct from the caissons, owing probably to the longer time that would be required for opening the lock with caissons furnished with roadways which would have to be lowered before the caissons could be drawn back.

The supply of power from a single central station, with electrical transmission, for working several machines which are not in constant operation, should prove economical in the expenditure of power, just as hydraulic power is economically and conveniently

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employed as the motive power for dock appliances at various places in a port. The system has in this instance the special advantage that the works for which the power is required are all concentrated near the lock and in the Inner Basin at Zeebrugge, so that the distance of transmission is small; whilst electrical transmission is well suited for temporary purposes across irregular ground, and where works are in progress, conditions under which the laying of pipes for hydraulic power would be impracticable.

Prospects of the Bruges Ship-Canal.—The undertaking is being carried out with two objects in view, namely, to provide a port of call for sea-going vessels, and to restore to Bruges its importance as a commercial centre by giving it deep-water access to the sea.

The value of Zeebrugge harbour as a port of call will depend upon the shelter and facilities offered, and the advantages afforded for rapid dispatch to passing vessels, as compared with neighbouring ports. The open state of the harbour to the east will render it inconvenient for vessels during north-easterly gales. The breakwater will protect the harbour from the north and west; but considering that the fetch in a north-westerly direction is about 100 miles, and that the breakwater will extend into a depth of about 4½ fathoms at low water of spring tides, and will not be sheltered by outlying sandbanks, it appears probable that the sea will occasionally dash over the parapet wall during north-westerly storms, and render the quay unsuitable for a time for the purposes of commerce. The embankment forming the approach to the breakwater is intended to arrest the drift of sand along the shore, and the open viaduct has been introduced to allow the littoral drift of silt to pass along unimpeded; but deposit from these sources cannot fail to occur within the sheltered area of the harbour, which, however, can be periodically removed by dredging. The prospects of trade at Zeebrugge harbour appear uncertain; for the long-established passenger traffic of the neighbouring ports of Ostend and Flushing is not likely to be quickly drawn away to a new port, not apparently possessing any superior advantages in position; and vessels would not readily be diverted from their proper course, and delayed in their voyage, in order to discharge a small portion of their cargo.

The provision of a deep-water channel of 26¼ feet to 28 feet between Bruges and the sea, thereby converting it into a seaport, is of considerable interest as an enterprising attempt to revive the commercial importance of a mediæval town long ago cut off from the sea, and whose main attractions at present consist in the old relics of its past grandeur. The revival of an ancient seaport

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which has lapsed into relative insignificance, in comparison with the great expansion of sea-going traffic at favourably situated ports in recent times, owing to the silting up of its approaches when an increased depth is required to accommodate modern vessels, is not, indeed, necessarily an empty dream; for Rotterdam, which was a small old-fashioned town when the Author first visited it rather more than thirty years ago, has been transformed into one of the principal seaports of the Continent by the considerable improvement in depth and directness of its access to the sea effected since 1863. Rotterdam is remarkably well situated for serving as the eastern port in the line of communication between Atlantic and English ports and central and eastern Europe; but Bruges might have had a good prospect of competing for some of this traffic if it had been made a seaport some years ago, and if it was the only Belgian seaport leading to Brussels and thence to various parts of Europe. The ship-canal will undoubtedly be advantageous to the trade of Bruges, and assist its development; but considering the improvements effected within recent years in the approach to Ostend, and the extensions of that port in progress, it does not seem probable that Bruges will be able to secure much of the traffic with Brussels and the east and south of Europe. Antwerp, moreover, with its well-sheltered deep-water connection with the sea, its extensive accommodation for shipping, and its favourable situation in relation to the coal and iron districts of Belgium, and for trade with central and eastern Europe, has not merely become by far the chief commercial city of Belgium, but actually stands second only to Hamburg amongst the seaports of the Continent. Bruges, accordingly, when it again becomes a seaport, will have a hard struggle to become a commercial centre, with powerful rivals on each side of it for sea-going traffic and trade, belonging to the same nationality; for its near neighbour Ostend possesses equal advantages as regards situation, and superior accommodation for shipping; and Antwerp, situated considerably further inland to the east, has given incontestable proof of its exceptionally favourable position for trade with the interior of Europe, by its remarkably large and rapid development, Fig. 23, Plate 6.

There is, indeed, another Belgian inland seaport, Ghent, which might appear to give some promise of a prosperous future for Bruges; for Ghent, being connected with the estuary of the Scheldt at Terneuzen by a ship-canal, enlarged between 1870 and 1885, having at present a depth of only 21½ feet, and a width at the bottom of 55¾ feet and at the water-level of 183¾ feet, and passing for nearly half its length through Dutch territory, has, in spite of

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its proximity to Antwerp, had a notable and steady increase in the tonnage of the vessels entering it during the last 13 years, namely, from 254,094 tons in 1884 to 603,372 tons in 1897,[1] Fig. 23, Plate 6. Ghent, however, is considerably nearer to Brussels, Mons, Charleroi, and Liége, than Bruges; and though the Ghent-Terneuzen Ship-Canal is at present less deep and wide than the Bruges Ship-Canal is being made, a convention was agreed upon with Holland, in 1895, for the enlargement of the canal to a depth of 26½ feet and a minimum bottom width of 64 feet, which works are in progress; whilst a considerable extension of the docks at Ghent and other improvements have been decided upon. Accordingly, Ghent will possess a communication with the Scheldt estuary by ship-canal very similar in dimensions to that being constructed between Bruges and the sea, and a more sheltered approach; whilst Ghent is not merely more favourably situated than Bruges, but will also offer superior accommodation for shipping. Bruges will therefore not be able to compete on equal terms with Ghent for sea-going trade; and it is by no means certain that Bruges will have a similarly rapid development as a seaport. The commercial prospects, indeed, of Bruges would have been much brighter if the ship-canal could have been made many years ago, before the trade routes by Antwerp, and to a much smaller extent by Ghent and Ostend, had been fully established; and the best chance of a revival of the prosperity of Bruges would be such a great development of the sea-going traffic at Belgian ports as to render the accommodation at Antwerp, Ghent, and Ostend, inadequate to cope with it.

Improvement and Extension of the Port of Ostend.

Ostend is at present the only seaport of Belgium situated actually on the sea-coast; for Nieuport, a port to the west of Ostend with very little trade, is about 2 miles up the River Yser. The port of Ostend, like other North Sea and Channel ports, such as Dunkirk, Calais, Boulogne formerly, and Dieppe, comprises an entrance channel guided and protected across the beach by jetties, maintained formerly by sluicing basins, and now mainly by sand-pump dredgers, leading to a tidal basin dry at low water, in which fishing-boats lie, and also to an outer harbour which communicates, through a lock, with an inner harbour in connection with the

[1] "VII° Congrès international de Navigation, Guide-Programme," Brussels, 1898, pp. 169, 173, and 248, and Plates 9, 10, and 16.

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inland canals of the district. Docks entered by locks from the outer harbour have been gradually added to these ports, when the deepening of the approach channel has caused a development of trade.[1]

The origin and growth of Ostend Harbour were described by the Author in his Paper on "Harbours and Estuaries on Sandy Coasts," in 1882; and a plan of the port at that period is appended to the Paper.[2]

Recent Works at Ostend Harbour.—Since 1882 important improvement works have been carried out. In 1885 an extension of the tidal basin was made on the northern side, and its entrance altered, Fig. 17, Plate 6. The outer portion of the entrance channel, 490 yards in length, which was 328 feet wide between the guiding jetties at the outlet, and only 197 feet wide at the narrowest part, was widened out in 1889 to 492 feet and 328 feet respectively, by the reconstruction of the west jetty. In 1890, a careening bank for fishing-boats was made on the eastern side of the entrance channel, on a portion of the site of the outer sluicing basin, with its apron about 3¼ feet above low water of spring tides; and a naval basin has been formed to the south of it, in which the State postal steamboats are repaired. A direct line of railway was constructed in 1896, connecting the Ostend Station with the Ostend-Dover steamboat pier, necessitating the partial filling up of the sluicing basin to the south of the outer harbour, which has consequently been done away with, and its site appropriated for extensions of the quays and docks in progress, Fig. 17, Plate 6.

Dredging Channels of Ostend Harbour.—The approach channel beyond the jetties was formerly maintained by the ebbing current from the outer harbour and the scour from the sluicing basins, at a minimum depth of about 6½ feet below low water of spring tides; and a small sand-pump dredger was first employed in 1880, which increased the depth by about 2¼ feet.[3] In 1882, work was resumed with a larger dredger; and in 1884, the approach channel had been deepened to 20⅓ feet below low water, which was subsequently maintained, and the outer part widened, by a yearly dredging outside and in the jetty channel of between 98,000 and 235,500 cubic yards. The inner channel and the outer harbour were

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[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 1, and Plates 1 and 2; and "Harbours and Docks," p. 143, and Plate 1.

[2] Minutes of Proceedings Inst. C.E., vol. lxx. p. 10, and Plate 2, Fig. 1.

[3] "VII^e Congrès international de Navigation, Guide-Programme," p. 265.

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deepened by dredging in 1887, to 13 feet below low water of spring tides, the average rise of tide at springs at Ostend being 15 feet; and this depth was fairly maintained in the main channel by the discharge of land waters from the inner harbour, and the scour from the inner sluicing basin, so long as these means of scour could be employed with regularity. Silt, however, accumulates very rapidly in recesses and side channels beyond the influence of the scouring current, and often the presence of vessels in the outer harbour necessitated stopping the sluicing from the inner harbour; whilst the bad state into which the sluices from the inner harbour have fallen, involving frequent interruptions, and the abandonment of the inner sluicing basin, have greatly favoured the accumulation of silt in the outer harbour and channels. Accordingly, the annual amount of dredging with a bucket dredger needed for maintaining the depth of these parts of the port, which ranged formerly between 85,000 and 117,700 cubic yards, has been greatly increased since 1895.

The Stroombank formerly extended in a continuous line in front of Ostend,[1] with a depth of only 8¼ to 10 feet over it at low tide, thereby rendering the deep channel between the inner and outer roadsteads very circuitous; but in 1890–91, a western channel was dredged across the bank in a north-north-westerly line, having a depth at the present time of 20 feet at low tide, and a width of 550 yards including the side slopes. The success attending the formation of this channel led to the commencement, in 1896, of a direct channel dredged in a west-north-westerly direction across the Stroombank, which has now a depth of 18 feet at low tide and a width of 380 yards, and is preferred by the sailors to the western channel. A third channel is being dredged to the east, to cut off the Stroombank from the shore, and thereby facilitate the passage of littoral currents for the maintenance of the depth in the inner roadstead.

The improvement works recently effected in the approaches to the port and the entrance channel, have resulted in an increase in the trade of the port; for the tonnage of the vessels entering the port, which was about 124,000 tons in 1881, rose to 176,823 tons in 1894 and attained 356,321 tons in 1897, Fig. 23, Plate 6.

Extension Works in Progress at Ostend.—A large increase in the accommodation afforded by the port for shipping was decided upon towards the end of 1894, of which only the diversion of the branch of the Ostend-Bruges Canal, forming the southern boundary of the

[1] Minutes of Proceedings Inst. C.E., vol. lxx. Plate 1, Fig. 1.

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port, was in an advanced state at the time of the Author's visit. The other works, which were in an early stage, are shown in dotted lines on the plan of the present port of Ostend, Fig. 17, Plate 6. They comprise an extension of the naval basin used for repairing the mail steamers, together with a new entrance to it, 85½ feet wide, in a sheltered position, and the construction of a graving dock near it; also the extension of the outer harbour inland on the site of a portion of the present inner harbour; and the construction of a large new lock on the site of the former sluicing basin, opening into a side prolongation of the outer harbour, and leading to a long new dock communicating with a canal dock joined to the branch of the Ostend-Bruges Canal by a wide basin in which vessels will be able to turn round. The quays on each side of the new dock, and on the south-west side of the outer harbour extension, are to be amply provided with sheds and railway sidings; and a large sluicing basin is to be formed on the low ground to the east of the outer harbour, with an outlet into the upper end of the outer harbour, placed at the side so as not to interfere with the entrance to the inner harbour. The sluicing basin is to have six openings at its outlet, each 16½ feet in width; and its sill is to be 13 feet below low-water level, or nearly 13 feet lower than the sills of the previous outlets of the sluicing basins, which will very greatly augment the scouring power of the issuing currents, and maintain a good depth in the outer harbour, especially in its upper part and along its new line of quays. The lock leading to the new dock is to have a width of 59 feet, and an available length of lock chamber of 394 feet; and its sill being placed 14¾ feet below low water, will enable vessels of 23 feet draught to pass through the lock during 4½ hours, on the average, in each tide.

These works, which are being carried out partly by the State and partly by the town of Ostend, will greatly improve the condition of the port of Ostend. The relative facilities for trade which will be afforded by the ports of Ostend and Bruges when the works in progress have been completed, can be readily noted by comparing Figs. 2 and 16, Plate 5, with Fig. 17, Plate 6, as these three figures are drawn to the same scale. Bruges will have the advantage of a well-sheltered approach, except during easterly winds; but as regards the outer and inner quays, in shelter, ease of access, and convenience, the balance of advantages will apparently be in favour of Ostend. Moreover, Ostend already possesses an increasing trade, and an important postal and passenger service; whereas Bruges will have to create a trade as a seaport. The

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impartiality and enterprise, however, of the Belgian Government, which are almost essential to the due carrying out of the principle of State aid to commercial development, are clearly manifested by the large financial grants made simultaneously for the advancement of two neighbouring seaports, which, in the event of the Bruges Ship-Canal attracting any important amount of traffic, cannot fail to become commercial rivals.

New Works at the Port of Antwerp.

The total tonnage of vessels entering the port of Antwerp is ten times that of Ghent, the second port in Belgium, and nearly eighteen times that of Ostend, which occupies the third place, though in 1855 it only about equalled the present tonnage at Ostend, and in 1865 that of Ghent, the great increase in the trade of Antwerp having commenced about 35 years ago, and continued since then, with only occasional slight temporary checks, at an increasingly rapid rate up to the present time, Fig. 23, Plate 6. Accommodation for vessels is provided at Antwerp by docks on the low-lying land to the north of the town, constructed for the most part at the expense of the municipality, and by river quays along the right bank of the Scheldt in front of the town, constructed by the State; and the port is in communication with the inland waterways of the country by means of the Scheldt and its tributaries, and the Campine Canal to the Meuse, which is reached through the Asia Dock, Fig. 18, Plate 6.

Recent Works, and Present Condition of the Port.—The docks have been gradually extended to endeavour to meet the increasing requirements of the port; but the most recent and important extensions are the Lefebvre (formerly Africa) and America Docks, constructed in 1883–87, and the reconstruction and prolongation of the river quays carried out in 1877–84 at a total cost of £3,314,000, which includes purchase of land for widening the quays and the thorough equipment of the quays. The progress of these works has been recorded at various times;[1] and descriptions of the works after their completion have been written by their respective engineers.[2] The Lefebvre and America Docks

[1] Minutes of Proceedings Inst. C.E., vol. liii. p. 313; vol. lvii. p. 376; vol. lxxiv. p. 312; vol. lxxvii. p. 428; and vol. lxxxv. p. 457.

[2] International Maritime Congress, London, 1893, Proceedings of Section II., p. 66; Annales des Travaux Publics de Belgique, vol. xlvii., 1889, p. 1; and Minutes of Proceedings Inst. C.E., vol. ci. p. 330.

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added a water area of 54¼ acres to the Antwerp Docks, with a depth of 30 feet, and 3,120 lineal yards of quays; whilst the new quays along the Scheldt have a length of 3,830 yards with an average width of 330 feet, and extend over an area of 80½ acres. The quay works alone, with the barge docks of 15 acres near their upper end, cost £1,744,500; and the line of quays, in a continuous curve, concave towards the river, was arranged so as to regulate the Scheldt on its right side, cutting off a projecting point at one part, and extending a varying distance into the river at other places, the improvement in depth thereby effected in the navigable channel being aided by dredging, so that there is a depth of from 26¼ to 33 feet alongside the quays at low water, the rise of tide at springs being 15 feet. The laying of foundations by means of compressed air has been very extensively resorted to for the quay-walls in the Scheldt, where the wall has been built at a maximum distance of 500 feet out from the right bank, and founded in the alluvial bed of the river at a depth of 34 feet to 52 feet below low water. Two floating landing-stages have been placed in recesses formed in the quays.

The port of Antwerp at the present time comprises the river quays just referred to, with their sidings, sheds, and hydraulic travelling cranes; eight docks in communication with one another, provided with two entrances into the river, opening out of the Kattendyk Dock and the Little Dock, and connected on the east side, through a lock, with the Campine Canal; six graving docks; and three small docks, near the southern end of the quays, for river craft, with a lock leading into the river, Fig. 18, Plate 6. The entrances to the docks are 81⅓ feet and 59 feet wide, with depths over their sills of 25 feet and 22⅔ feet respectively at average high water; and they are generally opened 1½ hour before high water, and closed 1½ hour after high tide. A large lock for placing the Lefebvre Dock in direct communication with the Scheldt, was commenced in 1893; but the works were suspended by the occurrence of a settlement, and they have not been resumed owing to the proposals which are under consideration for the rectification of the Scheldt below Antwerp. The total area of the docks is 159 acres, and the length of quays round them 11,770 yards; the sheds cover an area of 31¼ acres, and the sidings on the dock quays amount to over 29 miles in length; and there are numerous travelling and fixed cranes, a sheer-legs, and a coal-tip, almost wholly worked by hydraulic power.[1] The America Dock is

[1] "Notice sur le Port d'Anvers," Brussels, 1898, p. 19.

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devoted to the petroleum trade, and has tanks on its quays capable of storing over 17,000,000 gallons; and its quays are lighted by electricity, and the tanks isolated as far as possible, to guard against fire.

Extension of Quays in Progress at Antwerp.—As the large additions to the docks and quays have not sufficed to keep pace with the rapid increase in the trade of the port, it was decided in 1895 to extend the river quays 2,190 yards further up the Scheldt, from the south-western end of which an embankment is to be formed, about 1,100 yards long, to connect the line of the quay-wall with the right bank of the river higher up, and thus regulate the current, Fig. 18, Plate 6. The new quay-wall will present a concave face to the river, like the existing one; and the depth alongside, which is to be increased to 26¼ feet at low water by dredging for a width of 250 feet, will be readily maintained by the current. A third landing-stage is to be placed in a recess in the new quays; and the drainage culverts and intercepting sewers discharging at present on the river bank will have to be extended under the new quays. The new works were commenced early in 1898 by Messrs. Hersent and Son, who contracted in September 1897 to carry them out for the sum of £432,200 in three years.[1]

The continuous quay-wall, which will be situated entirely in the river, is being founded, like the previous quay-wall, which it joins, by means of compressed air in a bottomless caisson suspended and floated out between two barges, and gradually sunk in place by excavating inside it to a sufficiently firm foundation in the alluvial bed of the river, being weighted on its roof by the quay-wall built up gradually, and by ballast in the void in the enclosed space; and the caisson, forming the working chamber, is finally filled with concrete through the vertical shafts, Figs. 19 and 20, Plate 6.[2] The interval of 1½ feet, necessarily left between each 98½ feet length of foundation, and about 3½ feet between the walls, is filled up to 3¼ feet above low water with cement concrete, which is keyed into the wall by filling up two vertical grooves purposely left at the ends of each length; and a continuous wall is built on the top from about 3 feet above low-water level. The system, indeed, resembles the method of construction adopted by Messrs. Couvreux and Hersent for the earlier quay-wall, described

[1] "Construction des Nouveaux Quais en amont d'Anvers," H. Hersent et Fils, p. 13.

[2] *Ibid*, Plate 3, Figs. 3 to 7.

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in detail elsewhere,[1] but with modifications in the size and position of the caisson in relation to the wall above, the arrangement of the shafts, the accompanying plant, and the section of the quay-wall. Thus the caisson is 98½ feet by 31 feet instead of 82 feet by 29½ feet, and it projects 8 feet in front of the base of the wall instead of only 4 feet; whilst the new wall is 21⅓ feet wide at the base on the top of the concrete foundation in place of 23 feet, but wider near the top than the original wall to afford space for a subway in the wall for the hydraulic pipes. The increased width and projection of the foundation were ordered by the Government, to reduce the weight imposed upon the clay bottom, and to increase the stability of the wall in resisting the pressure of the filling at the back.

The quay-wall has a concrete foundation from the base of the caisson up to 24⅔ feet below low water; and from this level the wall is built of brickwork, with a dressed-stone facing from 2¼ feet below low-water level up to the top, which is coped with ashlar masonry, Fig. 21, Plate 6. The quays are to be given a width of about 330 feet, and are to be equipped at once, on the completion of a portion, with sidings, sheds, and travelling cranes, so as to be available for trade as soon as possible.

The regulating embankment continuing the rectification of the right side of the Scheldt above the new quay wall, is to be formed of sand faced with a layer of clay on the inner slope and on the top, with stone pitching bedded on a layer of clay from the top down to low-water level on the river side, and with brickbats and an outer facing of rubble stone from low water to the bottom, Fig. 22, Plate 6.

Proposed Rectification of River Scheldt below Antwerp.—The River Scheldt follows a remarkably favourable course above Antwerp, so that with the extensions in progress there will be a line of quays stretching for nearly 3½ miles along the right bank in a continuous curve concave to the river, and by side of which, therefore, the deep channel of the river is sure to remain. Below Antwerp, on the contrary, there is a very sharp bend near the entrance to the Kattendyk Dock, making the river turn at right angles to its previous course; and in the next 7 miles there are four bends, the two lower ones being sharp, which make the ebb-tide navigable channel pass over from one bank to the opposite one between the bends, and cause the flood tide to take a different

[1] Annales des Travaux Publics de Belgique, vol. xlvii. p. 1; Minutes of Proceedings Inst. C.E., vol. ci. 331; and "Harbours and Docks," p. 408, and Plate 8, Figs. 5 and 6.

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course to the ebb tide, forming blind channels in the sandbanks projecting from the convex bank of the bends, resulting in the appearance of a spit in mid-river connected with the convex shore at a bend, Fig. 18, Plate 6. Accordingly the beneficial effects of the improvement of the river above Antwerp on the tidal condition are impeded by the winding channel below; and it would be impossible to prolong the river quays much further along the right bank below Antwerp with the present irregular course of the river.

As far back as June, 1874, Mr. Stessels, the hydrographer of Belgium, proposed doing away with all the bends of the Scheldt between Antwerp and Lillo, by cutting a new channel for the river, starting from a little above the Kattendyk entrance, and only joining the river again below the lowest bend, a short distance above Lillo, as shown in dotted lines on Fig. 18, Plate 6.[1] This course has the advantage of providing a continuous concave right bank for nearly 5½ miles below Antwerp, very suitable for the improvement of the navigable channel and the extension of quays, in place of the tortuous irregular channel, with five awkward bends, which at present forms the approach to Antwerp. In August, 1874, Sir John Hawkshaw, who had been consulted by the Minister of Public Works on the improvement of the river near Antwerp, strongly urged the adoption of Mr. Stessels' scheme. The Belgian engineer, Mr. Maus, who had a long experience of the Scheldt, also pressed, in 1881, for the execution of this scheme, so that by greatly facilitating the passage of vessels along this portion of the Scheldt, the position of Antwerp as one of the principal seaports of the Continent might be assured.

At a conference held by the Belgian Society of Engineers in Brussels, in February, 1891, Mr. Dufourny brought forward another scheme, proposed by Mr. Bovie and himself, for the improvement of the Scheldt below Antwerp,[2] which aimed mainly at the partial rectification of the river by making a new channel for about 2 miles below Antwerp, with a concave right bank, along which quays could be made, and then a partial alteration of the channel down to the end of the bend round Fort St. Philippe, thereby greatly easing the sharp bends at Antwerp and the Fort, and doing away with the two flatter intermediate bends, but leaving the lowest bend just above Lillo unaltered, Fig. 18, Plate 6. The reasons put forward for this scheme, in preference to the direct cut, were the barring of this course by the construc-

[1] "Le Port d'Anvers, ses Améliorations," Brussels, 1897, p. 5, and Annex I.

[2] "Le Prolongement de la Rade d'Anvers en aval du Kattendyk," A. Dufourny, Brussels, 1891.

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tion of the America Dock right in its path, the demolition of a new fort and the rendering useless three other forts on the present course of the river necessitated by the direct cut, the prospect of the formation of a winding channel along the new cut, and the great cost it would entail. Mr. Dufourny sent the Author a copy of the Paper on the scheme submitted to the conference, asking for his opinion of the scheme, which was given in two letters in April, 1891. That opinion was to the effect that the winding scheme proposed might be the best attainable if the cost or other considerations rendered a direct diversion impracticable, but that with a continuous concave bank there was no prospect of the formation of a winding navigable channel, which, on the contrary, would be the inevitable consequence of a winding course as proposed, and that even if the existence of the America Dock and a new fort in the line of Mr. Stessels' cut prevented the execution of this scheme, it was still quite feasible to make a direct cut from Antwerp towards Lillo, avoiding both the America Dock and the fort, by adopting a somewhat straighter and therefore a somewhat less perfect course than the original proposal, as shown by lines on a plan sent by the Author to Mr. Dufourny in April, 1891, but yet far superior as a river improvement and for the extension of river quays than the winding scheme submitted to the conference.

When Mr. Franzius, the engineer of the Weser River, was consulted on the question of the improvement of the Scheldt below Antwerp by the Minister of Public Works, in the autumn of 1894, he at first stated it as his opinion that amongst the schemes submitted to him, the one proposed by Messrs. Bovie & Dufourny would satisfy every requirement.[1] Nevertheless, after a more thorough investigation of the subject, he finally arrived at the conclusion that, with the winding scheme the river would be still in danger of being blocked by ice, that it would present the inconveniences of a winding course for navigation, and would lengthen somewhat, instead of shortening, the distance from Antwerp to the sea. Accordingly, in his report of June, 1895, Mr. Franzius proposed a modification of the Stessels-Hawkshaw scheme, avoiding the America Dock, resembling very closely the course sketched by the Author for Mr. Dufourny four years earlier, but obtaining a somewhat sharper curve for the right bank near Antwerp, at the expense of commencing the regulation about halfway between the entrance to the Barge Docks and the entrance to

[1] "Le Port d'Anvers, ses Améliorations," Brussels, 1897, Annex A.

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the Little Dock, by bringing forward the line of quays into the river so as almost to reach the left bank at the projecting point opposite Antwerp, and cutting off a considerable slice of the point for the new channel.[1]

The engineer in charge of the tidal Scheldt, Mr. Pierrot, has recently revived the Stessels-Hawkshaw scheme in his report of June, 1897, presented to the Belgian Government, in spite of its involving the removal of the America Dock[2]; and he shows that this improvement would be quite compatible with a very large extension of the Antwerp Docks to the north of the Lefebvre Dock on the removal of the fortifications as proposed, which at present prevent any dock extensions to the north. Mr. Pierrot, moreover, proposes to retain as a large commercial dock the portion of the river which would be abandoned for the new cut, by putting a dam across the channel near each end, and affording it an outlet at its lower end by a canal and large lock entering the river in the concave bend opposite Lillo. He also advocates the regulation of the Scheldt below the diversion, extending into the estuary as far as opposite Waarde, so as to complete the improvement of the navigable channel down to deep water, and still further facilitate the access to Antwerp,[3] a problem for which the Author also endeavoured to find a solution in 1881.[4]

From some conversations with persons well qualified to judge, and with whom the decision will eventually rest, the Author gathered, during the meeting of the Brussels Congress, that the existence of the America Dock is not regarded as an insuperable objection to the formation of the curved cut between Antwerp and Lillo as originally designed. It is, however, a matter of regret that any works were allowed to be carried out in the line of the proposed cut, and that the execution of the scheme has been so long delayed. Considering the very rapid increase in the trade of Antwerp during the last 30 years, and the inadequacy of the large extensions hitherto carried out to meet the growing requirements of the vessels frequenting the port, it is of the highest importance that the proposed new channel should be carried out as soon as possible, for this work will not only effect a very great improvement in the navigable and tidal condition of the Scheldt below

[1] "Le Port d'Anvers, ses Améliorations," Brussels, 1897, p. 21 and Annex II.

[2] *Ibid*, pp. 5 to 14, and Annex VIII.

[3] *Ibid*, pp. 7 to 9, and Annex IX.

[4] "On the means of improving Harbours established upon low and sandy coasts like those of Belgium," L. F. Vernon-Harcourt (MS. and plans in the Library of the Institution), p. 143, and Drawing 29.

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Antwerp, but will also enable the river quays to be extended down the river, in proportion to the growth of the traffic, close alongside the navigable channel for a distance of 5½ miles, at the back of which there is an ample area of suitable land for the construction of docks with entrances affording direct access to the deep channel of the river. Since the Belgian Government has deemed it expedient to foster the trade of Ghent and Ostend by large grants towards the extension of these ports, and is spending a large sum to convert Bruges into a seaport, it is evident, from a comparison of the seagoing trade of Antwerp with that of Ghent and Ostend, Fig. 23, Plate 6, that Antwerp has a very strong claim to an exceptionally large measure of assistance in the effort to maintain successfully against powerful rivals, such as Rotterdam and Hamburg, and if possible to improve its very prominent position amongst continental seaports.

Concluding Remarks.—An endeavour has been made to indicate briefly in this Paper the principal maritime navigation works which are being carried on at the present time, or are in contemplation in Belgium, as gathered by the Author from his visits to the localities with the members of the Brussels Congress of 1898, and from the documents presented to the Congress. The Author desires to acknowledge his obligations to Mr. Van Gansberghe, the engineer-in-chief of the Bruges Ship-Canal Works, for drawings and other information relating to the 3,000-ton concrete blocks being constructed at Zeebrugge, and also the kindness of Mr. De Bruyn, Minister of Public Works, in giving him copies of the recent reports on the proposals for regulating the River Scheldt below Antwerp, and providing for the extension of the port.

The Author trusts that the Paper will prove to the members of the Institution that a considerable amount of information about the navigation works of the country visited can be obtained by attending the International Congresses on Navigation held periodically in various countries in Europe; and he also desires to draw attention to the large harbour, canal, and river works of an interesting character that may be seen in progress in Belgium during the next two or three years. The works described furnish evidence of the great solicitude entertained by the Belgian Government in the development of the maritime trade of Belgium, and the resulting increase in prosperity of that flourishing country.

The Paper is accompanied by two tracings from which Plates 5 and 6 have been prepared.

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(*Paper No. 3101.*)

(*Abridged.*)

"Hydraulic Gold-Mining."

By JOHN ROBERT RICHARDSON.

HYDRAULIC mining may be defined as the removal and washing of gold-bearing gravels by means of water under high pressure, delivered upon the bank through a pipe and nozzle. This method of mining is now carried on more or less in many parts of the world, but its birthplace and natural home is California; in no other district has it ever been practised on such a large scale or with so much success. The earliest record of hydraulic mining dates from 1852, when Mr. Edward E. Mattison, of Connecticut, first used a stream of water under pressure through a raw-hide hose fitted with a wooden nozzle. It was soon found that the material was removed in this way much more quickly and cheaply than by hand. From this crude beginning has developed the hydraulicking of the present day, in which industry nearly £20,000,000 is invested, the original leather and canvas hose with 1-inch nozzles having developed into 40-inch wrought-iron pipes with 9-inch nozzles, with water under a head of 450 feet.

In order to hydraulic successfully there must be: (1) a very large supply of water at high pressure; (2) facilities for obtaining the requisite gradient for the sluices; (3) a good tip for disposing of the tailings and débris; and (4) a very large body of material containing gold in remunerative quantities. As the water used for hydraulicking is derived chiefly from small streams fed by rain and melting snows, the operations of small companies which have no storage-reservoirs are necessarily more or less confined to the rainy season, and rarely continue more than a month or so after the dry weather sets in. Companies hydraulicking on a more extensive scale have large storage-reservoirs, and are thus able to continue working with but little interruption during the whole of an average year. On the Yuba, Bear, Feather, and American rivers, there are reservoirs constructed with an aggregate storage-capacity of about 50 billion gallons. As hydraulic mining is almost invariably carried

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on at a considerable elevation, and as the water required for the monitors must be under pressure, it follows that these storage-reservoirs must be situated high in the mountains. They are formed by damming some mountain stream in a narrow ravine. Usually no other preparation is made, the bed of the reservoir not being touched, nor the trees felled.

The Bowman main dam belonging to the North Bloomfield Company is one of the largest dams in California. The catchment-area of the reservoir formed by it is nearly 29 square miles; but as there are, higher on the same streams, smaller dams, which in average years retain all water flowing into them, this is generally reduced to about 19 square miles. The full capacity of the reservoir is 918,000,000 cubic feet of water, and it has an area of over 500 acres. The dam was first built of timber cribs to a height of 72 feet, but a few years afterwards it was much strengthened by stone and raised to 96 feet.[1]

Owing to their great expense, masonry dams are rarely met with in hydraulic mining. The most frequent forms are those built of cribs of unhewn timber logs strongly bolted together, filled with loose stones, and faced with planking nailed on and battened. Stone dams are always built of rough undressed material, the faces, both up and down stream, being built of very large stones, some weighing as much as 3 tons, fitted together as closely and as carefully as the variation in their size will permit. The interior of the dam is filled with loose rubble of much smaller size. The water-faces are always lined with planking. For small depths, earthen dams are sometimes employed.

From the reservoir to the mines the water is brought in ditches and in flumes, which, owing to the very irregular surface of the country and the great distances to be traversed, are frequently very difficult and costly to construct. In California there are thousands of miles of such flumes and ditches. Indeed in the foot-hills and valleys there is very little free water, as it is all the property of one or other of the large companies. The two most striking examples of important ditches are the North Bloomfield main ditch, of which the length is 55 miles, the size 8 feet 8 inches by 5 feet by 3½ feet deep, and the cost £93,341; and the Milton Company's main ditch, of which the length is 80 miles, the size 7 feet by 4 feet by 3½ feet, and the cost £92,599. The total length of the ditches owned by the South Yuba Water

[1] "A Practical Treatise on Hydraulic Mining in California," A. J. Bowie, New York, 1885, p. 106.

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Company amounts to 128 miles, the cost having been £220,000. Altogether there are about thirty large water companies whose water is principally used for mining. Even by making long detours it is not always possible to carry the water entirely in ditches, and consequently flumes, pipes, and tunnels have often to be used. In Butte County, on the route of the Miocene Company's main ditch, a flume, 4 feet wide and 3 feet deep, was carried for a distance of 486 feet round the face of a perpendicular cliff. The brackets were made of T-rails bent to L shape, one end being let into the rock. From the end of the vertical length a $\frac{3}{4}$-inch round bar was fastened by means of an eye, the bar in its turn being fastened to the face of the rock. The supports were placed 8 feet apart and were tested to 15 tons. The flume hangs 118 feet above the bed of the ravine and 230 feet below the top of the cliff. This arrangement was adopted in order to avoid the construction of a trestle that would have been in places 180 feet high. Along the line of the same ditch there is a trestle 1,088 feet long and 80 feet high. There are many instances of flumes carried on trestles between 50 feet and 75 feet high. Flumes are made on steeper gradients than ditches, and consequently they are of smaller cross-sectional area.

For crossing very wide and deep valleys inverted siphons are used. Wrought-iron pipe is almost exclusively used, as it can easily be laid down or removed as required, and as it presents the advantages of lightness combined with strength. The thickness of the plates depends upon the pressure of the water and the size of the pipe; it may, however, be taken to vary between about $\frac{3}{8}$ inch and $\frac{1}{16}$ inch, the sizes mostly used being between $\frac{1}{4}$ inch and $\frac{1}{16}$ inch thick. For light pressures, say under 200 feet head, pipes are generally single-riveted all over; but for more important lines and higher heads they are usually double-riveted on the longitudinal seams and single-riveted on the circular seams. The riveting is almost always performed cold. The pipes are usually made into lengths of about 12 feet to 20 feet, and are slightly bell-mouthed at one end and tapered at the other, the last three or four rivet-heads being countersunk inside the bell-mouth at one end, and outside on the taper at the other.

In laying the pipe-line the lowest length is placed in position first. A piece of canvas or old sacking is then wrapped round the small end of the second length, which is then forced into the bell-mouth of the first. For this purpose rope slings are placed round both lengths, and long wooden levers are used through the slings to draw the pipes together. At the same time the second length is

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driven in by blows from a heavy hammer on a piece of wood held across the top end of the pipe. No riveting, bolting, or other means are adopted to hold the pipes together. In this way the pipes can be laid round curves or over uneven ground without the use of bends or elbows, unless the curves are very sharp. When the whole line is laid, if there is any leakage, as is generally the case, a few barrowloads of sawdust or horsedung are placed in the pressure-box at the top of the pipe, and this working down into the leaks will make the pipe perfectly tight even under great pressure. For very high heads, lead joints are occasionally used, in which case a nipple is riveted into one end of each length; this slips into the next length, the pipe itself being butt-jointed. A broad iron ring is placed over the joint, lead is run in between, and caulked from both sides.

The water is brought by ditches, flumes and pipes, in the manner described, to a "pressure-box" situated at a sufficient elevation to give the jet the required force. The site selected for it should be one that will give the greatest possible head above the working face. At the same time it must be near enough to avoid an excessive length of pipe. As the water enters the pressure-box from the ditch, it is usually measured, all measurements of water being made in California in miner's inches. This unit is a somewhat variable quantity, as it differs with different companies. It may, however, be assumed to be the quantity of water that will pass through a hole 1 inch square under a given head in a given number of hours. The number of miner's inches used depends upon the number of square inches in the aperture, but as the heads vary between 4½ inches and 12 inches above the centre of the aperture, and as the time is in some cases 10 hours, in others 11 or 12, and often 22 hours, the amount of water is very variable. As an average, it may be taken that the head is 7 inches, and that the discharge is through a 1½-inch plank. The usual measuring device is shown in *Figs. 1.* A short length of flume, A, connects the ditch and the pressure-box; and there is a plain sluice-gate, D, to regulate the flow from the ditch; the pressure-board, B, having an aperture, say 6 inches high. The pressure-board is 4 inches above the top of the aperture, or 7 inches above the centre of the opening. Battens are fixed across the flume at F and C behind the pressure-board. Between the pressure-board and the battens, narrow boards are inserted so as to restrict the width of the opening to the number of square inches required. At E there is an overflow-spout, to carry off any excess of water. The overflow-water is taken up again by

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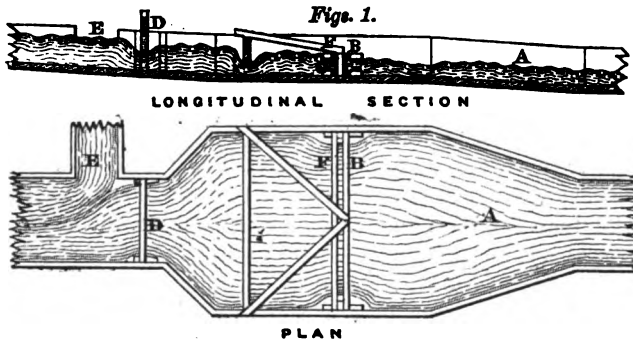
the ditch at some lower point. In working, the size of the opening in the pressure-board having been set at the number of miner's inches required (576 in the case illustrated), the gate is raised until water enough flows in to fill the flume to the top of the pressure-board, and to maintain it at that constant level. This gives a head of 7 inches from the centre of the opening. The quantity of water that passes through every square inch in the opening at that pressure, in twenty-four hours, is one miner's inch.

The pressure-box consists of a large wooden tank generally built of 1½ or 2-inch planks. The planks are not grooved and tongued, but are fitted close together, a ½-inch batten 3 inches wide being nailed over the joints on the inside. At the end of the box nearest the ditch there is a sand-box, to catch any sand or pebbles carried by the water, which is drawn off at intervals through the sluice. A grating of 1-inch by 3-inch slats, is set edgeways to the

Figs. 1.



Device for Measuring the Flow of Water.

current to catch dead leaves, sticks and other floating matter. At the opposite end of the box the upper length of the pipe is carefully fitted and caulked with sacking, etc. The box must be large enough, and there must be a sufficient supply of water always flowing into it to maintain it full when the pipe is working. When the valve is closed at the lower end of the pipe, the surplus water escapes by the overflow. Occasionally more than one pipe is taken from the same pressure-box, but generally only one. The last length of the main supply is generally funnel-shaped, but after that all the pipe is uniform in diameter to the sluice-gate. When a main pipe has to supply more than one nozzle, Y-pieces are inserted, with a valve on each, so that the water can be shut off close to the main, and either branch continue working while the other is being re-laid, an operation frequently needed as work progresses.

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The pipe terminates in a discharge-pipe, known as a "monitor." There are various forms, but those in most general use are made with 7-inch to 15-inch inlet, and 5-inch to 11-inch outlet. They are supplied with several sizes of nozzles, but those from 5 inches to 7 inches are chiefly used. Although most of the pipe-line, except where it is laid in a curve, is merely placed on the surface of the ground, the discharge-pipe and the nearest length or so are securely fixed. The monitor is bolted to a solid piece of timber, which is secured to the bed-rock or anchored to large boulders. It is placed as near to the bank as possible, consistent with the safety of the miners, so as to take full advantage of the force of the water. The stream of water between the end of the nozzle and the face of the bank is generally between 100 feet and 150 feet long; even at this distance the disintegrating power of the water is enormous. The quantity delivered by a single nozzle amounts at some of the mines to about 1,000 miner's inches to 1,200 miner's inches, or 1,500 cubic feet to 1,800 cubic feet a minute, under a pressure of 150 feet to 500 feet head. It is difficult to state the exact duty (or quantity of material washed in 24 hours) of 1 miner's inch, as it depends so largely on the nature of the gravel, on the pressure of the water, and on the gradient of the sluices. The jet can, however, nearly always bring down from the bank much more material than can be carried away by the sluices, for if the latter were set at such a gradient as freely to carry away all the gravel disintegrated, they would be too steep to retain the gold effectually.

An attempt was made by the State Engineer of California to determine the average duty of the miner's inch.[1] The result was as follows:—

Stream.	Quantity of Water Used and Discharged into Beds of Rivers in 24 Hours.	Estimate of the Duty of the Miner's Inch.	Amount Moved.
	Inches.	Cubic Yards.	Cubic Yards.
Dry Creek	833,250	3·5	2,916,375
Butte Creek	24,000	3·5	84,000
Feather River	1,259,363	3·5	4,407,770
Yuba River	5,458,171	3·5	19,103,598
Bear River	1,117,082	3·0	3,351,246
Dry Creek No. 2	44,229	3·0	132,687
American River	1,914,500	4·5	8,615,250
	10,650,595	3·5	38,610,926

[1] Ninth Annual Report of the State Mineralogist, Sacramento, 1890, p. 126.

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In a Paper contributed to the Ninth Annual Report of the California State Mineralogist, Mr. J. H. Hammond contends that this estimate of 3·5 cubic yards per inch is much too low. At the Hobson Mine in Placer County, with a bank 120 feet high, with the use of 500 inches under a pressure of 360 feet, and with a very light free gravel, the duty of the miner's inch was 24 cubic yards; this is exceptionally high. The Author's experience tends to show that the duty is between 4 cubic yards and 6 cubic yards.

Frequently the bank is so solid and compact that, notwithstanding the enormous power of the water, blasting has to be resorted to, in order to loosen the mass. The method adopted is to run a drift into the bank to a distance determined by the nature of the material, and by the height of the bank. As a rule the distance is about three-quarters of the height of the bank. From the end of this, cross-drifts are run at right angles; and in the ends of the cross-drifts the explosives are placed in boxes or kegs. Black blasting-powder is generally used, or low grade dynamite. The charge used, as a rule, is between 15 lbs. and 25 lbs. of powder for every 1,000 cubic feet of ground. When blasting has to be resorted to, it is usually carried out on an extensive scale, 8,000 lbs. to 15,000 lbs. of powder being used at a single blast, though there are many cases on record where much larger charges have been used. For instance, the Smartsville Hydraulic Mining Company fired a blast of 1,200 kegs of 25 lbs. each, moving ground 270 feet long, 180 feet wide, 100 feet deep. The cost of this blast was £1,200. At the Blue Point Mine, Nevada County, a single blast of 2,000 kegs, of 25 lbs. each, was exploded. At the Paragon Mine, Placer County, a blast of 700 kegs, of 25 lbs. each, was fired in a bank 150 feet high. At the Harriman and Taylor Mine, Gold Run, Placer County, a blast of 3,500 lbs. of giant powder No. 2 was used, which threw down 200,000 cubic yards of gravel. The largest blast coming under the Author's notice was made at the Blue Tent Mine, Nevada County, where a bank, 200 feet high, was thrown down by a blast of 43,000 lbs. of powder. A very large blast was made at the Dardanelles Mine, Forest Hill, Placer County. In this case the bank was 175 feet high, with a face 1,200 feet long. Five parallel drifts were run in 70 feet long, and 180 feet apart; and from the end of each of these drifts two cross-cuts, right and left, were run 70 feet each way, thus leaving a space of 40 feet between the ends. The powder, in 50-lb. boxes, was charged in lots of 1,000 lbs. to 1,500 lbs., in the ends of the different drifts. In each chamber three detonators were placed in

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the powder, and connected by insulated copper-wires with main leads brought outside through the main drift and coupled to an electric exploding battery. The drifts were then all well tamped with clay and boulders. When fired, the ground was bodily raised 4 feet or 5 feet, and thoroughly shattered. Though in this case boulders were used partly for tamping, they are not recommended, as they are extremely dangerous should the tamping blow out. It is best to use the gravel extracted from the drifts, and to see that it is solidly rammed in with wooden mauls or rammers. As the object of blasting is merely to shake and loosen the ground in order to make piping easier and more effective, a slowly lifting powder is best. For breaking up trees and large boulders too heavy to handle dynamite is used. When the boulders are small enough to be handled they are lifted out of the way and piled up by derricks. When the bank is more than 150 feet or so high it is generally worked in benches.

In practice the monitors are played mainly at the foot of the bank until this is so undermined that the top caves in and falls by its own weight; then the stream is played on the heap until all is washed away into the sluices, when the bank is again undermined. When working, the face of the bank should be kept as square as possible, carefully avoiding working into what is called a "horseshoe," as with high banks this is very dangerous to the men, as they are thus surrounded, and likely to be buried under a sudden cave. When two pipes are used on the same face, and the gravel caves freely, it is best to employ one pipe in bringing material down from the bank, and the other in washing away the fallen gravel into the sluices.

Sluices.—Among the most important conditions of hydraulic mining, and often the most difficult to attain, are an efficient gradient for the sluices, and a good tip for the débris. This may be easily understood when it is stated that from the larger mines upwards of 2,000,000 cubic yards are moved annually. Deep cañons are the most suitable for these purposes, especially those with torrential streams running through them, as, although these streams are insignificant during the summer months, during the winter and spring, when the snows are melting, they are rushing torrents which carry away many thousands of tons of débris. The gravel, as it is washed down by the jet from the monitors, is carried by the water into the sluices. These are large troughs paved in such a way as to form a surface for catching the gold. They are distinguished from flumes in that the latter are merely conduits to carry water, while sluices are prepared with false bottoms known

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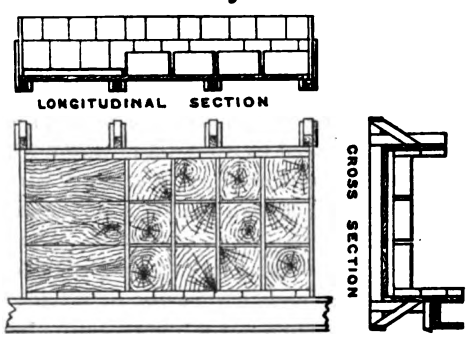
as "riffles," and are used for conveying the gravel being washed, and for extracting the gold from it. Where practicable the sluice-lines are always laid in the open, but frequently, owing to the natural lay of the ground, as, for instance, when piping is being done in a hollow, or when the ground is being worked in benches, shafts and tunnels in the bed-rock are necessary. These vary between a few hundred feet and several thousand feet in length. The tunnel of the North Bloomfield Company, Nevada County, for example, is 7,800 feet long, its size 7 feet by 8 feet, and cost £100,000.

Sluices are placed in the tunnel; and as a rule the material is carried in open bed-rock cuts to the head of the sluice-line. The sluices are long boxes or troughs, usually from 4 feet to 6 feet wide, 18 inches to 3 feet deep, 12 feet long, and are constructed of 1½-inch or 2-inch planks. Where possible they are placed in a straight line. The gradient is determined by the nature of the material to be washed. For light free gravel about 4 per cent. to 4½ per cent. is best, but for coarse, heavy, and strongly-cemented gravel a gradient of from 6 per cent. to 8 per cent. is necessary. The length of the sluice-line may be between 500 feet and several thousand feet. The rule is to make the line sufficiently long to thoroughly grind and disintegrate the material, and thus to free the gold. Hard cemented gravel and material containing pipe-clay require much longer than free light gravel, and often need several drops on the line to thoroughly break them up. The line is continually extended so long as the increased yield exceeds the expense. The bottoms of the sluices are paved to form riffles to catch the gold, and also to take the wear, which is always great. Wooden blocks and large stones have proved the best materials for the riffles at the Hidden Treasure Mine at Sunny South, Placer County; the Author has seen old mining car-wheels used with great success. Where wood blocks are used, they are square, 8 inches to 13 inches deep,

Figs. 2.



Sluice and Riffles.

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and set on end in rows across the sluice, each row separated from the other by a narrow wooden strip about 1 inch to 1½ inch thick. They are also sometimes wedged with soft pine between the sides of the sluice. The first few hundred feet of the sluice are generally paved in this manner, as block riffles of this description are very easy to remove and replace. The construction of the sluice and riffles is shown in *Figs. 2.*

Cast-iron riffles are also often used; they are made with the riffles either longitudinal or transverse. Where first cost is of importance, and where the gravel is light and does not contain a considerable proportion of heavy stones, riffles made in the form of grids from 1-inch by 6-inch timbers and covered with hoop-iron are very effective, and will last a long time. Riffles of this description were used with the greatest success at a mine at Clipper Gap, Placer County, with which the Author was at one time connected. Stone riffles are also often used. For the first few hundred feet the sluices are often built double, so that one side can be used while the other is being cleaned up. As the tail sluices are rarely cleaned oftener than once a year a single line is sufficient. By the side of the sluice, and forming part of it, is a small flume used to carry clear water when cleaning up.

When the operation of piping, or directing the jet against the bank, is being carried on, huge stones and large pebbles rush down the sluices with tremendous force. These are allowed to remain in the sluices for the first few hundred feet, as they are very useful for grinding and thoroughly disintegrating the gravel, and thus freeing the gold. Nor does their presence prevent the coarser gold from settling at the bottom and being retained by the riffles.

Under-currents.—In order to catch the fine gold, broad sluices called "under-currents" are used, the object of which is to extract all the coarse gravel and stones, and to make the stream pass over a very large area in the form of a thin sheet of water instead of in that of a confined rapid current several inches deep, as is the case in the sluices. The under-current should be if possible eight to ten times as wide as the main sluice, and 40 feet to 50 feet long. The water rushing down the main sluice carries the large stones over a grating, and tips them on to the bed-rock, while the fine material and a portion of the water passes through the grating and flows over the under-current tables, and out to a point where it is again taken up by the sluice-line, together with the water and gravel that may have passed over the grating, all the large boulders being left behind. From two or three to eight or ten under-currents are introduced into the sluice-line according to the requirements of

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the gravel being treated. When all is ready, water is turned on and piping commences. For the first half-day no mercury is used, but gravel and water are run down the sluices to swell the timber and thoroughly pack the boxes. The water is then stopped and a charge of mercury put into the sluices, the bulk of which is put into the first 200 feet to 400 feet, although a little is put into the entire length except the last 400 feet to 500 feet. The under-currents are also charged. The amount used as a single charge varies widely, but for a sluice, say 6 feet wide and 2,000 feet to 3,000 feet long, the first charge will be about three or four flasks. An under-current 24 feet wide will take about 80 lbs. Mercury is added day by day in diminishing quantity.

The sluices are carefully guarded to prevent theft, and the sluice-tenders are also kept busy walking up and down the line to see that no large stones and lumps lodge and choke the sluices; everything must be kept steadily moving down. When the mine is only run intermittently, stopping, for instance, at nights, the sluices are run full of gravel before turning the water off, as an additional protection. The length of time the sluices are run before cleaning up, depends upon the richness of the gravel, but a clean-up generally takes place once or twice a month to the first 400 feet to 600 feet, less frequently to the lower sluices, and the under-currents, and the tail sluices only once a season.

Cleaning up.—When it is intended to clean up, clear water only is run through the sluices until all the loose gravel is washed through. The water is then shut off, and only a very small quantity let in as required to wash the blocks and riffles, and to wash the amalgam down the box when wanted. The paving blocks are then removed in lengths of between 40 and 80 feet, leaving in one row of blocks at the end of each section, or placing in a temporary riffle. All the blocks or riffles are carefully washed into the sluice before being taken out, so as to free them from any amalgam; they are then piled to one side. As the blocks are removed, the gravel and amalgam slowly moves down the sluices, and men follow and scoop it up with sheet-iron scoops and place it in iron buckets. As the end of each section is reached, the remaining riffles arrest the amalgam. As much as possible is then scooped into the buckets; the riffle is then removed, and the remainder is washed down into the next section, where the process is repeated. Men also examine the whole of the sluices and pick out the amalgam from all the crevices and holes caused by nail-heads, etc. When as much of the sluice as desired has been cleaned up, the riffles and blocks are replaced, the worn por-

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tions renewed, a fresh charge of mercury is inserted, and piping recommences. Notwithstanding the violent action of the water and gravel at the upper end of the sluice-line, before any grizzlies have been introduced to separate the large stones, by far the largest proportion of the gold is found in the first few hundred feet. The distribution of the gold is approximately 80 per cent. in the first quarter of the total length, 5 per cent. in the under-currents, and 15 per cent. in the remainder of the sluice-line. These proportions are dependent to a great extent on the coarseness of the gold, on the nature of the gravel, and on the gradient of sluices, etc.

Retorting.—The amalgam taken from the sluices is carefully cleaned, to free it from all fine gravel, sand, and pieces of iron, etc., that may have collected in the riffles. It is then placed, a few pounds at a time, in buckskin, which is twisted so as to force through the pores of the skin all superfluous mercury, leaving inside the amalgam in firm, solid balls. The balls of amalgam are placed in an iron retort, the inside of which has been carefully lined with a thin wash of chalk or pipe-clay, to prevent the amalgam from sticking to the sides. The retort is closed and a pipe leading from it passes through a condenser, through which a continual supply of cold water is kept running. Under the retort a fire is placed, which volatilizes the mercury and causes it to pass through the pipe and condenser, where it is again condensed and caught. The fire is kept steadily burning until the distillation ceases. The retort is then allowed to gradually cool, when the gold is taken out, melted in a crucible, and cast into ingots.

Though the methods described of treating auriferous gravels by the hydraulic process seem at a first glance to be somewhat crude, the amount of gold lost by passing away in the tailings is not so great as would at first appear. No systematic sampling of either the gravel deposits or of the tailings is usually carried out, as is the case in most good gold mills, but an examination of the tailings impounded in débris cañons, etc., shows them to contain very little gold. No doubt some gold is lost, as is proved by the fact that, no matter to what extent the sluices are lengthened, or how many under-currents are introduced, the last few feet, or the last under-current will always catch some gold. According to Mr. J. H. Hammond, at the best conducted hydraulic mines at least 85 per cent., and in many cases upwards of 95 per cent., of the gold contained in the gravel is saved. Indeed, Mr. Louis Glass, formerly manager of the Spring Valley Mines, is of

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opinion that 95 per cent. is generally saved. In the opinion of the Author 80 per cent. is an average value.

As has been shown, the expense incurred in opening a hydraulic mine is very large, but the working expenses per ton of material treated are very small owing to the vast quantities of gravel treated; and thus huge deposits of auriferous gravels of the very lowest grade can be and are worked at a profit by this method. The gravel is rarely worth as much as 2*s.* per cubic yard, or say 1*s.* 4*d.* per ton, and is at some of the mines worth only 1*d.* per cubic yard, or approximately one-third of a grain of gold per ton. Trustworthy statistics as to cost of working and yield of gravel in hydraulic mines are difficult to obtain, as at very few mines are any records kept. The La Grange Hydraulic Company, and the North Bloomfield Company, did for some years keep systematic records, and the Table in the Appendix shows the result of sixteen months' working at the La Grange Mines, Stanislaus County. From this it is seen that the total expenses barely amounted to 3*d.* per cubic yard.

One of the greatest drawbacks to hydraulic mining is the difficulty of finding suitable ground on which to deposit the tailings. As far as the miner is concerned, a deep ravine with a torrential stream is all that can be desired; but here the agriculturist living in the valleys, and also the State authorities, step in, and proceedings have been taken against the miners on account of the injury done by the débris to the navigable rivers and the valley lands. For this reason hydraulic mining was practically at a standstill for some years in all those parts of the State that are drained by the Sacramento, San Joachin, Yuba, Bear, Feather, and American rivers and their tributaries. In the test case of Woodruff *v.* the North Bloomfield Company evidence was given by engineers to the effect that a total of 176,061,000 cubic yards of débris were brought down from the mines annually. There is no doubt that a large amount of damage was caused, but a much greater injury was done to the State at large by the stoppage of the mines. According to the official report of 1880, 43,546 acres of land suffered a depreciation of £519,526 or a loss to the State in taxes of £1,430 annually. At that time the mines affected were producing about £2,000,000 annually. In 1893 an Act of Congress was passed, by which a Commission was appointed, and authorized to issue permits to mining companies to mine by the hydraulic method, subject to their proving to the satisfaction of the Commission that the débris could be retained behind dams, in cañons, or elsewhere on their property.

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In conclusion, the Author desires to acknowledge the courtesy and assistance afforded him by Mr. Grayson and Mr. J. Ross Browne, Mining Engineers, and Mr. Yale, State Mineralogist, all of San Francisco, who, on the occasion of his last visit to California, placed much of their time at his disposal, and enabled him to obtain many of the details contained in this Paper.

The Paper is illustrated by drawings, from a selection of which the Figures in the text have been prepared.

APPENDIX.

La Grange Mines, Stanislaus County, California; Result of 16 Months' Hydraulic Mining.[1]

1,533,728 inches (2,159 cubic feet each) of water washed 2,275,967 cubic yards of gravel, which yielded 12,026·84 ounces, worth £46,379.

The disbursements were as follows:—

	Total.			Per Cubic Yard.	Per Ounce Metal.		
	£.	s.	d.	d.	£.	s.	d.
Water	3,461	10	6	0·36	0	5	9
Labour	16,469	3	0	1·73	1	7	3¾
Material	4,357	13	6	0·45	0	7	2¾
Official	2,248	19	9	0·23	0	3	8½
Contingent	625	3	6	0·06	0	1	0½
Taxes	226	2	0	0·02	0	0	4½
	27,388	12	3	2·85	2	5	5

Average value of ounce of metal (gold and silver) produced, £3 17*s.* 1½*d.*
Average yield per cubic yard of gravel, 4¾*d.*
Average amount of gravel washed per inch, 1·48 cubic yard.

[1] Ninth Annual Report of the State Mineralogist, Sacramento, 190, p. 183.

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(*Paper No. 3104.*)

"The Efficiency and Design of Surface Condensers."

By THOMAS ERNEST STANTON, D.Sc., Assoc. M. Inst. C.E.

THE influence of the efficiency of the surface condenser on the performance of a steam-engine is known to be considerable, and it is therefore important to determine the conditions of maximum efficiency, and the extent to which they may be realized in practice.

The Author considers the case of surface condensers in which steam is condensed on the outside of tubes through which water is circulating, and it is assumed throughout that the velocity and flow of the circulating water, which, together with the distribution of the cooling surface, secure the lowest possible condenser temperature, are the conditions of maximum efficiency of the condenser.

To this assumption it may be objected that by reducing the temperature of the condenser, the range of temperature in the cylinder is increased, and that this might produce an increased condensation of steam on the walls and passages of the cylinder. The general results, however, of careful experiments on both non-condensing and condensing engines seem to show that the temperature of the steam at exhaust has little effect on the condensation in the cylinder; and that for the same initial pressure, ratio of expansion and speed, the condensation is practically constant.[1] The experience of the Author bears out this view. A further confirmation is found in the effect, on the brake load of a steam-engine, of varying the supply of condensing water, *i.e.*, by altering the back pressure. The reduction of the back pressure as much as possible would therefore seem to be

[1] This would correspond to the case of Partial Condensation or Complete Re-evaporation as defined by Callendar and Nicolson, Minutes of Proceedings, Inst. C.E., vol. cxxxi. p. 188.
Cotterill's "Steam-engine," p. 338.

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justified as a means of securing the maximum performance of the engine.

As an example of the importance of even a small reduction in the condenser temperature, in the case of an engine using steam at 200 lbs. per square inch pressure, the condenser temperature being 131° F., the theoretical work per lb. is 295·4 thermal units. If the condenser temperature is taken as 130° F., or one degree lower, the theoretical work is 296·5 thermal units, or an increase in the effective work of 0·37 per cent., showing that a reduction in the condenser temperature of one degree is worthy of consideration. It is obvious that a reduced condenser temperature may be procured without adding to the cooling-surface of the condenser, by increasing the flow of water through the tubes; but as this necessitates more powerful circulating-water plant, the advantage soon becomes doubtful.

The usual method of design would seem to consist in allowing a given area of tube-surface per pound of steam passing through the engine, or per horse-power, the diameter and length of the tubes being determined by custom. This area is usually between 1 square foot and 1·8 square foot per I.HP.; and the diameter of the tubes $\frac{5}{8}$ inch or $\frac{3}{4}$ inch, the thickness of the walls being about $\frac{1}{20}$ inch. The chief difficulty is to determine that length of tube, for a given value of the total cooling-surface, which will make the condenser most efficient, experimental data on this subject being much wanted.

It cannot be assumed that the heat abstracted from a given metal surface by water flowing over it is simply proportional to the difference of temperature between the surface and the water, since this would make the effect of the cooling-surface independent of the length of the tubes, and it has been pointed out by Professor Osborne Reynolds, that the heat abstracted by water from a hot surface must depend on the velocity of the water and on the dimensions of the channel in which it flows.

In 1896 the Author succeeded in experimentally determining the relation between the velocity and rise of temperature of water flowing through a metal pipe of given diameter, the walls of which were maintained at a constant temperature,[1] and the results of these experiments were found to agree with the theoretical law of the transmission of heat as given by Professor Reynolds. This law may be stated as follows:—

[1] Philosophical Transactions of the Royal Society, vol. cxc. p. 67.

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Let L = the length of the pipe in feet,
d = the diameter of the pipe in feet,
u = the velocity of the water through the pipe in feet per second,
T_0 = the temperature of the pipe in Fahrenheit degrees,
t_1 = the initial temperature of the water,
t_2 = the final temperature of the water,
t_m = the mean temperature of the water,
and K, n and a constants which depend upon the condition of the metal surfaces; the values for smooth brass pipes being—

$$K = 0{\cdot}0105,$$
$$n = 1{\cdot}86,$$
$$a = 0{\cdot}004.$$

Then—

$$K L = \frac{d\,(930\,u\,d)^{2-n}}{1 + a\left(\frac{T_0 + t_m}{2}\right)} \log \frac{T_0 - t_1}{T_0 - t_2} \quad . \quad . \quad (1)$$

On the assumption that the temperature of the tubes in a surface condenser is constant throughout the length of the tubes, equation (1) may be used to determine the dimensions of the tubes and the velocity of the water which will give the best results.

As an example, the Author takes the case of a surface condenser of given cooling-surface, length of tubes and supply of water.

Let l = effective[1] length of tubes in feet.
n_1 = number of tubes.
s = total cooling-surface.
Q = supply of water in cubic feet per second.

Then—

$$n_1 \pi d l = s, \text{ and } n_1 u \frac{\pi d^2}{4} = Q;$$

$$\therefore u = \frac{4 Q l}{s d},$$

so that equation (1) becomes—

$$K l = \left(\frac{3{,}720\,Q\,l}{s}\right)^{2-n} \frac{d}{1 + a\left(\frac{T_0 + t_m}{2}\right)} \log \frac{T_0 - t_1}{T_0 - t_2} \cdot \quad (2)$$

[1] The "effective" length is the total length of the tubular waterway through the condenser: thus in a condenser with tube 7 feet long, in which the water circulates in one direction through half the tubes and returns through the other half, the effective length is 14 feet.

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and the efficiency of the condenser may be written—

$$\frac{t_2 - t_1}{T_0 - t_1} = 1 - e^{-\frac{c}{d}} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where c is a constant—an equation which shows that W $(t_2 - t_1)$, which is the heat abstracted, has its greatest value when d is very small; the conclusion being that the efficiency of the condenser will be greatest when the diameter of the tubes is reduced as much as possible. Such a diminution will increase the velocity of the water passing through the tubes, so that more power will be required to circulate the water; but even in extreme cases this would only amount to a few inches increased head of water, and in condenser design the diameter of the tubes might be advantageously reduced to $\frac{3}{8}$ inch or $\frac{1}{4}$ inch.

As a second example, the effect of the length of the tubes may be found for a condenser of given cooling-surface, diameter of tubes, and supply of water. In this case equation (3) becomes—

$$\frac{t_2 - t_1}{T_0 - t_1} = 1 - e^{-c' l^{n-1}}$$

where c' is a constant, which shows that the heat abstracted has its greatest value when (l) is greatest. The effect of making the tubes longer will be to increase the velocity of the water, as in the previous case, so that the frictional resistance will be slightly increased. Again, if the cooling-surface, length and diameter of tubes are fixed, equation (3) may be written in the form—

$$\frac{t_2 - t_1}{T_0 - t_1} = 1 - e^{-\frac{c''}{u^{2-n}}}$$

where c'' is a constant. The heat abstracted = D Δ u $(t_2 - t_1)$, where D = weight of 1 cubic foot of water, Δ = total area of the flow; and this may be written—

$$\left(T_0 - t_1\right)\left(1 - e^{-\frac{c''}{u^{2-n}}}\right) D \Delta u.$$

Now, since the value of $(2 - n)$ is about 0·14, the variation in the value of $1 - e^{-\frac{c''}{u^{2-n}}}$ will be small, so that the heat abstracted is very nearly proportional to the velocity, *i.e.*, to the quantity, of the circulating water.

In marine engines the advantages of increasing the quantity of circulating water would eventually disappear when the extra

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power required for the circulation became equal to the increase in the power of the engine, due to the reduced exhaust-pressure; but in the case of land engines, where the supply of cooling water is unlimited, the flow may with good effect be made as great as practicable.

The law of communication of heat to water flowing through a metal tube would therefore indicate that in condensers, in order that the cooling-surface may be as efficient as possible, the length of the tubes should be made as large and the diameter as small as practicable, and that the supply of cooling water should be as great as possible. It must be noticed that the extent to which a fulfilment of these conditions will affect the efficiency of the surface condenser depends on the law of condensation of steam on the tubes; that is, in order to estimate the effect on the performance of the engine, of a change in the dimensions of the tubes and in the flow of water, it is necessary to know the relation between the temperature of the steam in the condenser, and the dimensions of the tube and velocity of the water.

An experimental determination of the rate of condensation of steam at a given temperature on a metal surface of given temperature has recently been made, for the case of comparatively high-pressure steam, by Messrs. Callendar and Nicolson,[1] and is stated to be, 0·74 thermal unit per second per square foot per 1° F. difference of temperature at 300° F.

Now for an engine using 20 lbs. of steam per I.HP. per hour, and assuming a cooling-surface of 1 square foot per HP., this would entail a transmission of not more than 20,000 thermal units per hour, or 5·56 thermal units per square foot per second, corresponding to a difference of temperature of 7·5° F. between the steam and the surface at the above rate. From actual determination of this difference of temperature in surface condensers, it would seem that the rate of condensation of low-pressure steam on the tubes is considerably less than the above, whether due to the reduced density, or to the difficulty of the access of the steam to the centre tubes. Messrs. Callendar and Nicolson do not seem to have made experiments as to the effect of the density of the steam on the rate of condensation, although it is commonly assumed[2] that this rate will be proportional to the surface exposed per pound of steam, *i.e.*, will be inversely

[1] Minutes of Proceedings Inst. C.E., vol. cxxxi. p. 147. Also Report of the British Association for the Advancement of Science, 1897, p. 418.

[2] Cotterill's "Steam-engine," chap. 9.

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proportional to the density of the steam. It therefore became necessary to further investigate the rate of condensation of steam by direct experiment on the tubes of a surface condenser.

Determination of the Rate of Condensation of Steam on the Tubes of a Surface Condenser.—It appeared evident that the air which is discharged with the exhaust steam into a condenser would affect the rate of condensation considerably, so that the size and speed of the air-pump would have an influence on the condensation. According to this view, any experimental expression for the rate will involve a constant, depending on the dimensions and speed of the engine. The Author was unable to make any direct temperature observations on the condenser tubes, so that the surface temperature, T_0, was estimated from the temperatures and flow of the circulating water by substitution in the equation (1)—

$$K l = \frac{d\,(930\,u\,d)^{2-n}}{1 + a\left(\frac{T_0 + t_m}{2}\right)} \log \frac{T_0 - t_1}{T_0 - t_2},$$

the values taken for the constants being those already noted, $K = 0{\cdot}0105$; $n = 1{\cdot}86$; $a = 0{\cdot}004$.

By the kind permission of Professor Hele-Shaw, a number of observations were made on the surface condenser of the experimental marine engine in the Walker Engineering Laboratories, University College, Liverpool. This condenser contains one hundred and fifty-two brass tubes, $\frac{5}{8}$ inch diameter, 7 feet long, placed horizontally, the effective length being 14 feet. The circulating water is estimated by a float in a tank provided with a rectangular notch.

The observations consisted in noting the actual temperatures and pressures, as shown on a mercury-gauge, of the steam in the condenser, when the supply of circulating water was varied. It was found that the observed temperature of the steam was in general agreement with that calculated from the pressure. The values of T_0 corresponding to given values of the temperature of the steam were then calculated, by substitution in equation (1) as described above.

Observations were made under the most widely varying conditions possible, and the results obtained were consistent, and may be shortly stated as follows:—

1. For a given rate of condensation, the difference of temperature between the steam in the condenser and the surface of the tubes depends on the density of the steam.

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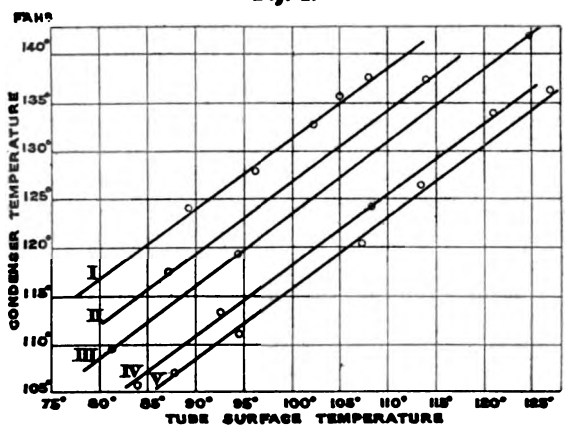
2. For a given rate of condensation and speed of air-pump, the temperature of the steam in the condenser is a linear function of the temperature of the tubes.

As an illustration the following Table of results may be quoted :—

Temperature F. of the Steam in the Condenser. T_s.	Temperature F. of the Tube Surface. T_0. (Calculated.)	Condenser Pressure. Lbs. per Square Inch.	Difference of Temperature Between the Steam and the Metal Tubes. $T_s - T_0$.
°	°		°
142·5	125·0	3·08	17·5
119·5	94·3	1·66	25·2
109·7	81·1	1·25	28·6

Taking the two extreme cases in this Table, it is seen that

Fig. 1.



while the density of the steam has diminished in the ratio of $\frac{1}{2\cdot34}$, the difference of temperature has increased in the ratio of $\frac{1\cdot63}{1}$. Again, if points are plotted with T_s and T_0 as ordinates and abscissas respectively, it is found that they lie on a straight line whose inclination to the base is constant for the condenser and air-pump experimented upon.

Some of these results are shown in *Fig. 1*, curves III and IV.

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It is seen that in all cases the inclination of the line is the same, showing that the relation between the temperature of the steam and the temperature of the surface of the tubes may be written—

$$T = m T_0 + c.$$

In the experiments quoted, m has the value 0·782; the value of the constant c depending on the speed of the air-pump and the quantity of steam discharged. At the normal speed, and condensing 28 lbs. of steam per minute, the value of c was 46·5.

By the kind permission of Professor Osborne Reynolds, similar observations, made on the surface condenser of the experimental engine in the Whitworth Engineering Laboratory, Owens College, by Mr. George Wilson, M.Sc., for the Author, are here stated. This condenser contains two hundred and eighty-three horizontal brass tubes, $\frac{3}{8}$ inch diameter, 4 feet long, the effective length being 4 feet, so that the conditions of flow were very different from those of the preceding case. The plotted results of these trials, shown in *Fig. 1*, curves I and II, agree with the others in confirming the truth of the summary of results already given. The chief point to be noted is that, in each of the four cases shown in *Fig. 1*, the slope of the line was independent of the quantity of steam condensed per minute. It was also found that, by assuming a different value for the constants in equation (1), the relation was still linear, the value of m depending on the constants.

To determine the effect of a variation in the speed of the air-pump, and also in the area of the cooling-surface, would demand experimental research which the Author has hitherto been unable to undertake.

It would seem probable that in all surface condensers the relation between the temperature of the steam in the condenser and the surface temperature of the tubes, will be of the above form, the value of the constant, c, depending on the efficiency of the air-pump and the general dimensions of the condenser.

The Calculated Effect of Varying Conditions of Flow.—Assuming that, in cases which occur in practice, the condenser-steam temperature can be expressed as a linear function of the surface temperature of the tubes, then the efficiency of the condenser can be determined under various conditions.

In all the cases which follow, it is assumed that the engine runs at a constant speed, and discharges a given weight of steam into the condenser per minute, the variation in the surface temperature simply affecting the temperature of the condenser steam.

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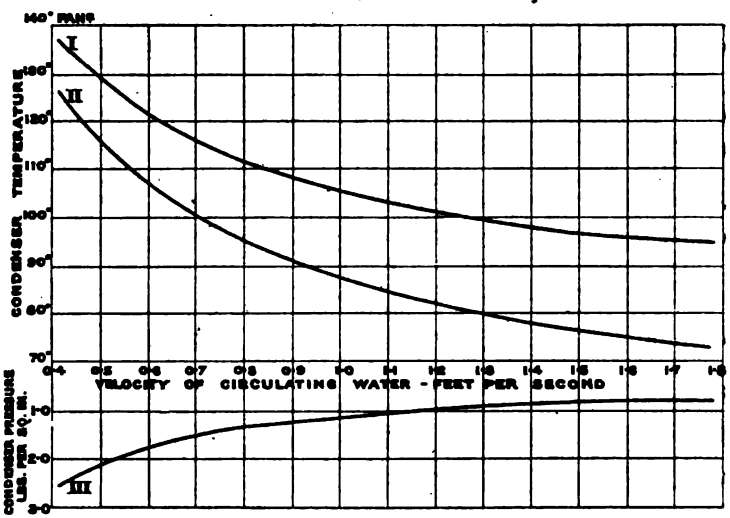
Case I.—The Supply of Water at a given Temperature being Unlimited, to Determine the Effect of an Increased Amount of Cooling Water through the Tubes of any Surface Condenser.—As mentioned above, this was observed directly in the case of the condenser of the experimental engine at the University College.

The results are plotted in *Fig. 2*, in which the variation of the condenser-steam temperature with the velocity of the cooling water is shown in Curve No. I and also the corresponding difference of temperature between the condenser steam and the tube surface in Curve No. II. It is easily seen from the figures that, owing to the increase in this difference, the advantage due to the increased flow soon becomes small.

Fig 2.



Case II.—The Effect of the Length of the Tubes in a Condenser of given Cooling-Surface, Diameter of Tubes, and Supply of Water.—The mean condenser temperature may be taken to be, say, 120° F., and since the variation from this in actual practice will not be more than ± 15°, the increase or decrease in the heat discharged into the condenser, due to a change in the condenser temperature, may be expressed in a simple form. Thus, in Rankine's notation, the heat rejected into the condenser from an unjacketed engine is—

$$\left(\frac{H_1}{J} - h_3 - \frac{\text{work done per lb.}}{J}\right) \text{thermal units per lb.}$$

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Hence a change in the condenser temperature of $d\,T_c$ produces a change in the heat discharged equal to—

$$-d\,T_c + \frac{144\,x_2\,V_2}{J}\,dp\,;$$

and since, for temperatures near 120° F.—

$$dp = \{0{\cdot}047 - 0{\cdot}0011\,(120 - T_c)\}\,d\,T_c,$$

the change in the heat discharged is—

$$\left[\frac{144\,x_2\,V_2}{J}\,\{0{\cdot}047 - 0{\cdot}0011\,(120 - T_c)\} - 1\right] d\,T_c,$$

or, approximately—

$$\{0{\cdot}0092\,T_c - 1{\cdot}595\}\,d\,T_c \quad . \quad . \quad . \quad . \quad (1)$$

thermal units per lb.

In the above approximation the value of $x_2\,V_2$ for the steam at release is taken as the common value obtained in practice with unjacketed engines, *i.e.*, $x_2 = 0{\cdot}8$ and $V_2 = 56{\cdot}0$ cubic feet.

Let W = weight of water flowing through the condenser per second, then the expression (1) is equal to $W\,d\,t_2$, where t_2 is the final temperature of the cooling water. But in this case (p. 324)—

$$\frac{t_2 - t_1}{T_0 - t_1} = 1 - e^{-c'\,l^{n-1}};$$

therefore

$$W\,d\,t_2 = W\left[\left(1 - e^{-c'\,l^{n-1}}\right) d\,T_0 + (T_0 - t_1)\,c'\,(n-1)\,l^{n-2}\,e^{-c'\,l^{n-1}}\,d\,l\right]$$

$$= w\,\{0{\cdot}0092\,T_c - 1{\cdot}595\}\,d\,T_c$$

when w = weight of steam discharged per second.

Or since $$T_c = m\,T_0 + c,$$

the equation may be written—

$$W\left[\left(1 - e^{-c'\,l^{n-1}}\right)\frac{d\,T_c}{m} + \left(\frac{T_c - c}{m} - t_1\right)c'\,(n-1)\,l^{(n-2)}\,e^{-c'\,l^{n-1}}\,d\,l\right]$$

$$= w\,\{0{\cdot}0092\,T_c - 1{\cdot}595\}\,d\,T_c;$$

or

$$\frac{c'\,(n-1)\,l^{n-2}\,e^{-c'\,l^{n-1}}\,d\,l}{1 - e^{-c'\,l^{n-1}}} = \frac{w\,\{0{\cdot}0092\,T_c - 1{\cdot}595\}\,d\,T_c}{W\left(\frac{T_c - c}{m} - t_1\right)\left(1 - e^{-c'\,l^{n-1}}\right)}$$

$$- \frac{d\,T_c}{(T_c - c) - m\,t_1} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

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Now in all cases the ratio of the first term on the right to the second is small, never exceeding 0·03, so that, as a first approximation for the solution of (2)—

$$\log (T_s - c - m t_1)\left(1 - e^{-c' l^{n-1}}\right) = k \quad . \quad . \quad (3)$$

and a closer approximation gives—

$$\log (T_s - c - m t_1)\left(1 - e^{-c' l^{n-1}}\right) = \frac{w}{W} \frac{\left\{0{\cdot}0092 \frac{T_s^2}{2} - 1{\cdot}595\, T_s\right\}}{\left(\frac{T_s - c}{m} - t_1\right)\left(1 - e^{-c' l^{n-1}}\right)} + k' \quad . \quad (4)$$

when the small term in (2) is integrated, taking

$$(T_s - c - m t_1)\left(1 - e^{-c' l^{n-1}}\right)$$

as constant.

From the data of an actual trial the following values were obtained:—

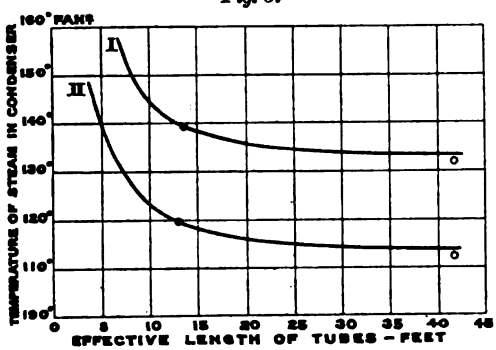
$T_s = 119{\cdot}6°$	$c = 46{\cdot}5$	$c' = 0{\cdot}2007$
$t_1 = 43{\cdot}3°$	$l = 14$ feet	$m = 0{\cdot}782$

so that substituting in (4)

$$k' = 3{\cdot}63.$$

The curves in *Fig. 3* are plotted from equation (4), the constant

Fig. 3.



in each case being determined by an experiment with the above values t_1, l, c, c' and m. These curves refer to the case of a condenser having a tube-surface of 176 square feet. No. I is

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calculated for a supply of cooling water of 15·5 lbs. per lb. of steam; and No. II for a supply of 25 lbs. per lb. of steam.

As an obvious experimental verification of equation (4), suggested by Mr. Donaldson, of University College, the condenser tubes were connected in series by means of baffle-plates fixed at the ends, so that the effective length of the tubes was 42 feet. A careful trial gave results closely agreeing with the calculated results, the observed temperatures being in each case however about 2° lower than the calculated temperatures. These are indicated by the small circles in *Fig. 3*. This is accounted for by noting that the condenser tubes, not having been cleaned for 6 or 7 years, were covered with a deposit, which reduced their efficiency, and made the value of K probably 0·08 to 0·09. It will be seen from the curves in *Fig. 3* that the increase in efficiency due to lengthening the tubes diminishes rapidly, the limiting length in this case being probably 25 feet.

The observed effect of lengthening the tubes from 14 feet to 42 feet was to increase the brake HP. of the engine by 1 per cent., the conditions being shown in the following Table:—

—	Cooling Surface of Condenser.	Length of Tubes.	Circulating Water per Minute.	Condenser Temperature.	Condenser Pressure.	Release Pressure.	Boiler Pressure.
	Square Feet.	Feet.	Lbs.	°F.	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.
No. 1 . .	176	14	700	119·6	1·66	14·0	115·0
No. 2 . .	176	42	700	112·5	1·36	14·0	115·0

Case III.—The Effect of varying the Diameter of the Tubes in a Condenser of given Cooling Surface, Length of Tubes, and Supply of Water.—In this case from equation (2), page 323, it is seen that the value of

$$d \log \frac{T_0 - t_1}{T_0 - t_2}$$

is constant for given values of t_1 and t_2; hence from an observation of the surface temperature, and discharge of heat in a condenser with tubes of given diameter, an approximate estimate can be made of the surface temperature in a condenser of equal cooling-surface and length of tubes, but of different tube diameter.

As an example, the condenser tubes of the experimental engine were 14 feet long and 0·63 inch diameter, the value of the temperatures for a given trial being:—

$$T_0 = 95·0° \qquad t_1 = 48·0° \qquad t_2 = 88·2°$$

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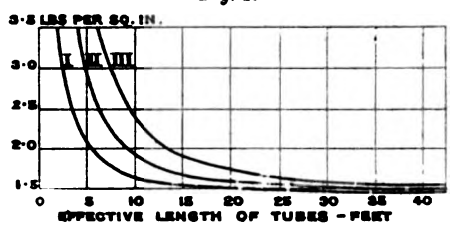
The calculated values of T_0, for diameters of $\frac{7}{8}$ and $\frac{3}{8}$ inch, under these conditions are 101·5° and 89·9° respectively, from which the condenser-steam temperatures are estimated to be 125·9° and 116·8°. Assuming, then, that the values of the condenser temperature for a given cooling-surface, supply of heat, and supply of cooling water, with a length of tube of 14 feet, are 125·9°, 119·6° and 116·8°, when the diameters of the tubes are $\frac{7}{8}$, $\frac{5}{8}$ and $\frac{3}{8}$ inch respectively, the curves calculated from equation (4), p. 331, can be calculated for each and compared. These curves are shown in *Fig. 4*, Numbers I, II, and III, referring to pipes $\frac{3}{8}$ inch, $\frac{5}{8}$ inch, and $\frac{7}{8}$ inch diameter respectively, the corresponding pressures being plotted, and the limiting length of tube for each case can easily be estimated. As an example, to secure a condenser pressure of 1·63 lb. per square inch, with the given supply of steam and cooling water, the lengths of the tubes should be—

Diameter. Inch.	Feet in Length.
$\frac{7}{8}$	26·8
$\frac{5}{8}$	18·2
$\frac{3}{8}$	10·0

Fig. 4.



It is probable, however, that, when the condenser tubes become coated with a deposit from the water flowing through them, the efficiency in transmitting heat will diminish, and lengths of tube greater than those in the above Table will be necessary to secure the temperature required.

These results may be stated in a simple form by noting that in the equation of heat transmission, *i.e.*,

$$K\dot{l} = \left(\frac{3{,}720\ Q}{S}\right)^{2-n} \frac{d}{1 + a\left(\frac{T_0 + t_m}{2}\right)} \log \frac{T_0 - t_1}{T_0 - t_2},$$

when Q and S are constant, the condition of equally effective transmission for different arrangements of tube is—

$$\frac{l^{n-1}}{d} = \text{constant}.$$

Hence, if this ratio be determined for a given condenser of known effective performance, the length of the tubes in an equally efficient condenser of the same cooling-surface, made with tubes of different diameters, can be at once determined.

Results as Applied to the Design of Surface Condensers.—The law

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of the transmission of heat shows that in a condenser of given surface for maximum efficiency the length of the tubes should be as great as possible; and this is confirmed by actual observation. As regards diameter of tubes, it is also shown that condensers in which the ratio $\frac{l^{n-1}}{d}$ is constant will be equally efficient. It is clear that in practice that diameter of tubes should be chosen which offers the least resistance to the passage of water. Now the resistance in a tube has been found by Professor Reynolds[1] to be proportioned to $\frac{l\,u^n}{d^{3-n}}$ for water at a given temperature; and under the conditions that the supply of cooling water and the total surface is constant, u is proportional to $\frac{l}{d}$; hence the frictional resistance is proportional to $\frac{l^{n+1}}{d^3}$, and if $\frac{l^{n+1}}{d}$ is constant, the resistance is proportional to l^{4-2n}. The resistance is therefore least when the diameter of the tube is the least practicable; and the most efficient design will be secured by using small tubes of as great a length as is consistent with the extreme limit of resistance allowed.

In conclusion it may be pointed out that the above theory assumes that the flow of water through the tubes is always "turbulent" as distinguished from the case of "steady motion," *i.e.*, that the velocity of flow through the tubes has a value greater than that given by:—

$$V_c = \frac{P}{84{\cdot}7\,D} \text{ feet per second,}$$

where D = diameter of the tubes in feet.

T = temperature of the water in centigrade degrees.

$P = (1 + 0{\cdot}0336\,T + 0{\cdot}000221\,T^2)^{-1}$

and which is the critical value of the velocity as determined by Professor Osborne Reynolds.[2] In many cases in which the supply of cooling water is limited, it may happen that the velocity of circulation is less than this critical value, which, it must be noted, applies to the case of water at a uniform temperature. Experiments made by the Author[3] show that when rapid changes of temperature are taking place the motion is "turbulent" at

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[1] Philosophical Transactions of the Royal Society, 1883, p. 976.

[2] *Ibid*, 1883, p. 948.

[3] *Ibid*, 1883, p. 70.

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velocities considerably below the critical value, so that it may be assumed that in a surface-condenser the motion is always turbulent.

As regards the position of the tubes the Author considers the best results would be obtained by placing the tubes vertically. The objection to the horizontal position is that the hot water tends to accumulate in the upper part of the tubes, thus rendering the upper surface the least effective for condensation, while at the same time the condensed steam collecting on the lower surface will tend to check the condensation. That the water should, as far as possible, be made to pass down the vertical tubes is seen from the fact that this condition in water which is being heated will promote unsteadiness of the motion, and also that the part of the tube which is most free from water accumulated on its outer surface is the surface of maximum condensation. Experiments made by the Author and quoted in the following Table confirm this view:—

COPPER TUBES 18 INCHES LONG, 0·422 INCH DIAMETER, PLACED VERTICALLY IN A CYLINDRICAL CASING AND SURROUNDED BY STEAM AT ATMOSPHERIC PRESSURE, WATER FLOWING ALTERNATELY UP AND DOWN THE PIPES.

Velocity of water in feet per second.	Flowing up Tubes.			Flowing down Tubes.		
	Initial Temperature.	Final Temperature.	Rise.	Initial Temperature.	Final Temperature.	Rise.
	°	°	°	°	°	°
0·804	47·8	96·7	48·9	47·8	110·3	62·5
1·63	47·8	78·0	30·2	47·8	83·0	35·2
2·12	46·7	73·2	26·5	46·7	77·5	30·8
4·14	54·3	74·1	19·8	54·3	74·9	20·6

The Author desires to express his indebtedness to Professor Osborne Reynolds and Professor H. S. Hele-Shaw for their kind permission to make observations on the surface condensers at Owens College and University College, and to Mr. George Wilson, M.Sc. of Owens College, for supplying valuable experimental data.

The Paper is accompanied by four drawings, from which the Figures in the text have been prepared.

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(*Paper No. 3169.*)

"Note on the Pressure of Grain."

By WILFRID AIRY, B.A., M. Inst. C.E.

SINCE his Paper on "The Pressure of Grain"[1] was written, the Author has found that the expressions—

Case I.
$$\begin{cases} \tan\theta = \mu + \sqrt{\mu \cdot \dfrac{1+\mu^2}{\mu+\mu'}} \\ P = \gamma \cdot \dfrac{h^2}{2\tan\theta} \cdot \dfrac{\tan\theta - \mu}{1 - \mu\mu' + (\mu+\mu')\tan\theta} \end{cases}$$

Case II.
$$\begin{cases} \tan\theta = \sqrt{\dfrac{2h}{b} \cdot \dfrac{1+\mu^2}{\mu+\mu'} + \dfrac{1+\mu^2}{\mu+\mu'} \cdot \dfrac{1-\mu\mu'}{\mu+\mu'}} - \dfrac{1-\mu\mu'}{\mu+\mu'} \\ P = \gamma \cdot \dfrac{b}{2} \cdot (2h - b\tan\theta) \cdot \dfrac{\tan\theta - \mu}{1 - \mu\mu' + (\mu+\mu')\tan\theta} \end{cases}$$

are reducible to the following equations—

Case I. $$P = \gamma \cdot \frac{h^2}{2} \left\{ \frac{1}{\sqrt{\mu(\mu+\mu')} + \sqrt{1+\mu^2}} \right\}^2$$

Case II. $$P = \gamma \cdot \frac{b^2}{2} \left\{ \frac{\sqrt{\dfrac{2h}{b}(\mu+\mu') + (1-\mu\mu')} - \sqrt{1+\mu^2}}{\mu+\mu'} \right\}^2$$

which considerably simplify the arithmetical work required in any given case. By means of this formula for Case II it can be shown that the pressure on the bottom of the bin has a maximum value (as appeared empirically from the Table on p. 349), and the value of h, the depth of grain in the bin, can be determined for that condition. Thus, for a square bin it is seen, as on p. 357 that the pressure on the bottom is $\gamma h b^2 - \mu' \cdot \pi$, where $\pi = 4b \times P$

[1] Minutes of Proceedings Inst. C.E., vol. cxxxi. p. 347.

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If, therefore, the pressure on the bottom is denoted by M the following equation is obtained—

$$M = \gamma h b^2 - \mu' \cdot 2\gamma b^3 \left\{ \frac{\sqrt{\frac{2h}{b}(\mu+\mu') + (1-\mu\mu')} - \sqrt{1+\mu^2}}{\mu+\mu'} \right\}^2$$

And by equating $\frac{dM}{dh}$ to zero and performing the reduction the value of h, which gives the maximum pressure on the bottom, is arrived at, viz.—

$$h = \frac{b}{2}\left\{ \frac{1+\mu^2}{\mu+\mu'} \cdot \left(\frac{4\mu'}{3\mu'-\mu}\right)^2 - \frac{1-\mu\mu'}{\mu+\mu'} \right\}$$

If $b = 10$ feet, and $\mu = 0{\cdot}466$, $\mu' = 0{\cdot}361$ (which are the values used for computing the Table on p. 349), the above formula gives $h = 35{\cdot}265$ feet, which agrees with the value of h for maximum pressure on the bottom arrived at by the Table referred to.

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(Students' Paper No. 401.)

(Abridged.)

"The Elastic Properties of Steel Wire."[1]

By ARCHER DAVE KEIGWIN, Stud. Inst. C.E.

THE experiments described in this Paper were undertaken to determine the behaviour of annealed and unannealed steel wire when subjected to tensile stress. The material used was drawn from one billet of steel into Nos. 8, 10, 12, 14, 16, 18, 20, 22 B.W.G. wires; and its analysis, for which the Author is indebted to Mr. J. E. Stead, of Middlesbrough, was:—

	Per cent.
Carbon	0·7
Manganese	1·124
Silicon	0·121
Sulphur	0·06
Phosphorus	0·053
Aluminium	0·007

Testing-Machine.—A machine of the steelyard type was employed for the tests. The frame consisted of two parts, the upper having vertical movement and carrying with it the steelyard and balance-weights with the clip for one end of the wire. The lower part formed the stand, to which is attached the gear for raising the upper part, and the clip for the other end of the wire. The steelyard carried a jockey-weight, by which small increments of load could be applied, a scalepan for the reception of heavy weights, and, at its end, a pointer, by bringing which to a fiducial line, the steelyard could be raised to give correct balancing. The jockey-weight was about 114 lbs., and for 100 lbs. load it had to be moved 1·75 inch along the steelyard. In this form the machine was, however, far too insensitive for the nature of the experiments the Author had to carry out, for since 1·75 inch represented 100 lbs. load, and the smallest wire broke at 55 lbs., it would have been impossible to determine the elastic

[1] This Paper was read and discussed at a Students' meeting on the 17th December, 1897.

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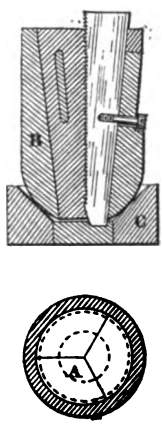
behaviour of the wire. The Author therefore made the machine ten times as sensitive by using a small jockey-weight and a counter-balance weight, so that when the jockey-weight was at zero the steelyard was in equilibrium. The machine was carefully calibrated by means of 100-lb. lead weights, which were first weighed on a calibrated spring-balance. Up to 1,000 lbs. every 100 lbs., and a few intermediate points, were tested, the jockey-weight and balance-weights being adjusted. The total length of steelyard represented 300 lbs., and for greater loads weights were placed in the scalepan, each representing 306 lbs. In this modified form the machine was found to work in a most satisfactory manner.

Cathetometer.—For measuring the elongation, two points on the wire were observed by a cathetometer constructed by the Author from a model of the Cambridge Scientific Company. The telescope was of the reading form, having an eye-piece with cross-hairs, and an object-glass capable of being easily moved by means of a pin sliding up and down a slot in the telescope-tube. The observation points were attached to the wire, and consisted of pieces of brass about ½ inch by ½ inch by ¼ inch, with a hole drilled through which the wire passed. A hardened steel set-screw, with a sharp point, was screwed through the side of the block into the hole and so jammed the wire, the sharp point just entering the skin of the wire. Attached to the block was a brass frame, having an aperture ½ inch by ¼ inch, across which was soldered a piece of phosphor-bronze wire, 0·001 inch diameter, forming the line to be observed. To render the wire more conspicuous, a piece of white paper was fastened on the back of the frame. There were two such frames, one at each end of the specimen; these were easily found by the telescope, and when so viewed the wire appeared the same size as the cross-hairs in the telescope; no difficulty was found in making the two lines coincide.

Figs. 1.



To overcome the difficulty experienced with the ordinary wire-grips the Author devised the form illustrated in *Figs. 1.* A steel cone about 2¼ inches long, with a taper of about $\frac{1}{12}$, was turned and a small hole was drilled down the centre through which the cone was split into three equal parts. The cone, A, is fitted into a hole of same taper in a steel cylinder, B, about

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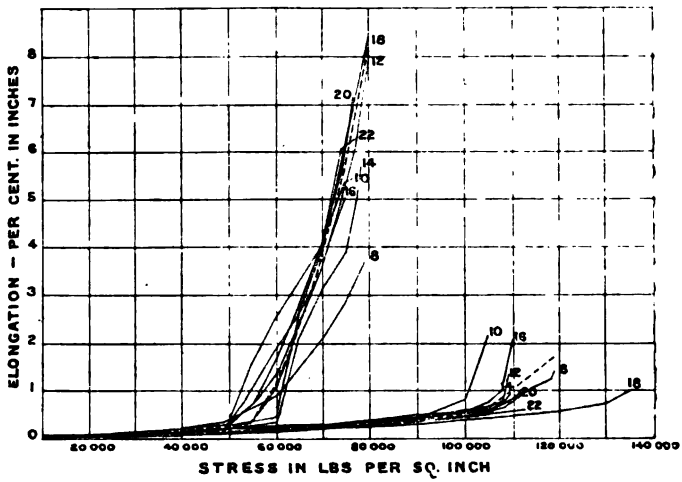
2¼ inches long, having the end rounded, the cylinder resting in a conical cup, C. The centre edges of the divided cone were made saw-like, and were slightly filed off towards the bottom and hardened. Three equidistant slots were cut in the cylinder, through which screws were fastened into the cone so that the pieces could slide up and down in the vertical plane only. The wire being placed between the wedges, they were tapped into place, and the cylinder resting on the cup would adjust itself so that the wire was pulled vertically, and the greater the pull the firmer became the grasp of the cones on the wire. This grip could take wires of every size without difficulty, and worked well.

Method of Procedure.—The testing-machine and cathetometer

Fig. 2.



having been adjusted, the latter being placed on a low table which was cemented into a concrete floor, the diameter of wire to be tested was carefully measured by a direct-reading micrometer screw; one end was then fixed into the top grip and the brass screens forming the points of observation were then slipped on, and the other end of the wire was fixed into the bottom grip and the screens finally adjusted to about 20 inches apart and illuminated by an incandescent-gas light. The weight, equivalent to a stress of 10,000 lbs. per square inch on the wire, was then calculated, and the jockey-weight was moved to the required position on the steelyard. The hand-wheel was then turned so as to apply the load and the steelyard was balanced so that the pointer came up

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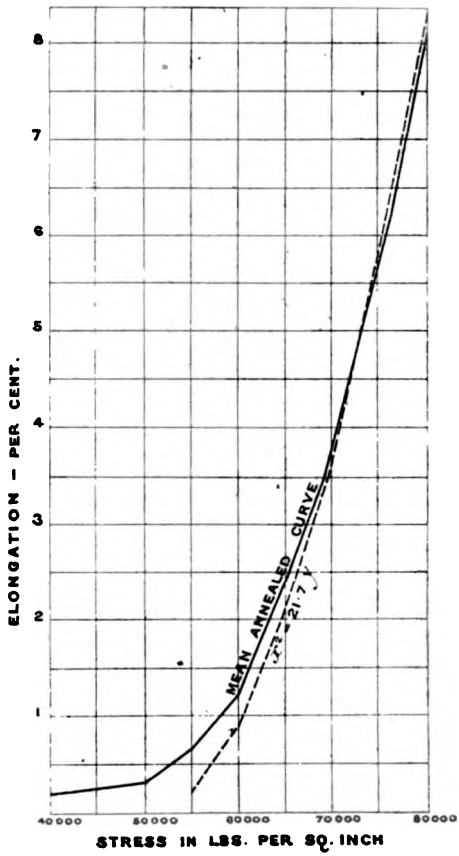
to the fiducial line. The heights of the screens were then observed by the telescope, and the readings, taken on the scale 20,000 lbs. per square inch stress, would then be taken in like manner, and so on until the wire broke.

Accuracy.—The greatest error found on the testing-machine, when calibrated, was less than 1 lb. in the first 100 lbs., and as this point was near the fulcrum, statical friction and the small turning effect might easily account for it, at the other points there were no appreciable errors; the accuracy, therefore, of the machine may be taken as well within ½ per cent. The cathetometer accuracy was considerably greater than this. The readings were taken in millimetres and ½ millimetres, the latter being divided into ten parts by the eye with the aid of a powerful lens.

Fig. 3.



Results. — The wires were first tested as received from the drawers. They were then annealed by cutting them up into convenient lengths and placing them together in a 1½-inch gas-barrel packed with quicklime. The barrel was heated in a gas-furnace to a bright-red heat and afterwards allowed to slowly cool; the length of time for this operation was about 5 hours. The results showed that the effect of annealing on the breaking load was to reduce it 39 per cent., the ratio of yield to break being lowered 13·3 per cent. The reduction of sectional area at the break varied between 43·5 per cent. and 51·8 per cent., an increase of 16·0 per cent.

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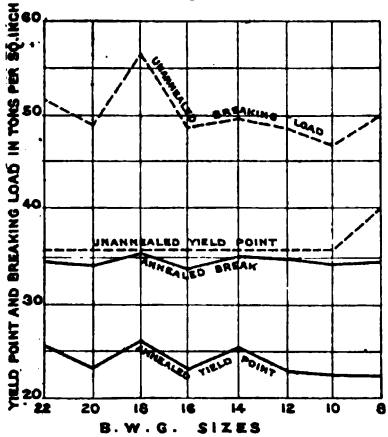
The mean curves of the annealed and unannealed wires are shown in *Fig. 2.* They were obtained by taking a mean of the three specimens of each wire, plotting them and then drawing the mean curve. In the annealed specimens the elastic limit is shown in a very marked manner, lying on a point between 50,000 lbs. and 60,000 lbs. stress, and all approach very nearly to the 80,000 ordinate which is the breaking stress. In the unannealed wires the yield point is harder to detect, and the breaking stress seems to be of a rather erratic nature, although the lines are exceedingly uniform up to 105,000 lbs. stress.

In *Fig. 3* is shown an enlarged part of the curve from the elastic limit, together with a curve of the form $x^2 = a\,y$, which is parabolic. For the upper curve the expression is $x^2 = 21{\cdot}7\,y$. So it will be seen that the mean curve lies across a parabola whose constant is 21·7, and therefore is for all practical purposes a parabola.

Fig. 4.



The breaking loads and elastic limits of the wires are illustrated in *Fig. 4.* It will be noticed that, whereas the breaking loads of the unannealed wires are not very definite quantities, the effect of annealing brings the breaking load down to a very definite point, which shows that the cause of the high breaking loads in the unannealed wires is due to mechanical work done on them. That such was the case in larger wire and rods has been shown by Mr. H. Allen,[1] and this also shows that such is the case with the smaller wires. There seems to be a slight increase in the breaking loads as the wires become smaller, but it is hardly perceptible; No. 18 has a distinctly higher breaking load than the others. A piece of No. 14 wire was drawn to No. 18 without annealing; this specimen broke at 69 tons, which shows again the increase of breaking load due to the drawing of the wire.

If the breaking loads of the annealed and unannealed wires be

[1] Minutes of Proceedings Inst. C.E., vol. xciv. p. 235.

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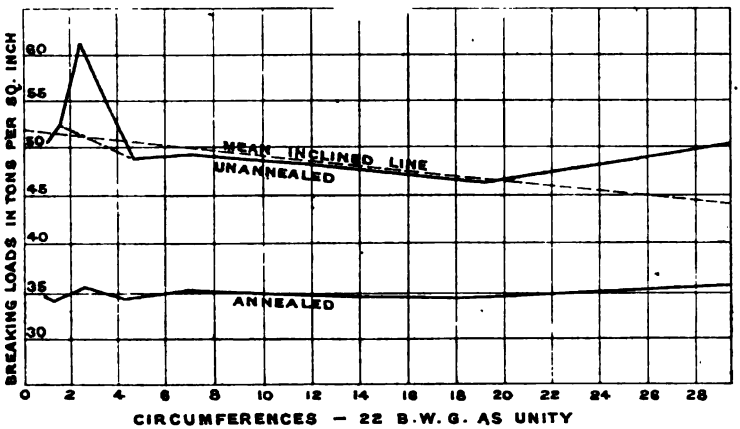
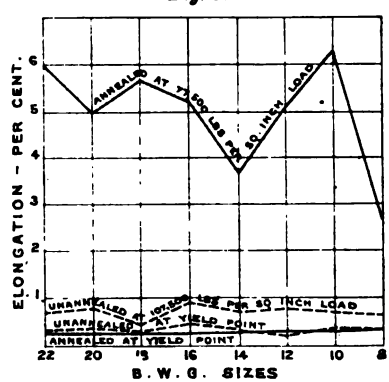
plotted on a circumference base, as in *Fig. 5*, it will be seen that the line of unannealed breaking loads has an inclination downwards to the horizontal line as the circumference becomes larger. If this line be produced it will be found to cut the line of

Fig. 5.



annealed breaking loads at a point where the circumference gives a diameter of about 3·25 inches. This theoretically would be the limit at which wire-drawing should cease to affect the breaking load. The line probably becomes asymptotic as it nears the horizontal line and consequently does not cut it.

Fig. 6.



The elongation per cent. of annealed and unannealed wires at the elastic-limit and breaking-load readings, in the case of annealed wire, is shown in *Fig. 6*. This occurred at a point where the stress was 77,500 lbs. per square inch, and in the unannealed wire 107,500 lbs. per square inch. The points show great uniformity, the unannealed elongation at 77,500 being the most erratic. This, however, is to be expected, as the material is in a very plastic condition.

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The following is a summary of the conclusions derived from the tests:—

(i) Steel when drawn into wire has its breaking load increased; the probable cause is that the molecules are pressed together, and therefore the density of the material is greatly increased;

(ii) When the wire is annealed the molecules assume their original state, and the breaking load is lowered to the breaking load of the billet from which the wire was drawn, in this case an average reduction of 39 per cent.;

(iii) The ratio of yield point to breaking load is lowered, viz., 36·7 per cent. and 31·8 per cent. for unannealed and annealed wire respectively, a reduction of 13·3 per cent.;

(iv) The ratio of extension at yield point and breaking load in unannealed wire, viz., 0·25 per cent. to 0·75 per cent., is increased by annealing to 0·25 per cent. to 5 per cent.;

(v) The reduction of area of break is increased 16·0 per cent. by annealing; and

(vi) That the mean stress-strain diagram is a parabolic curve for annealed wires.

The Author desires to tender his thanks to Professor D. S. Capper, Assoc. M. Inst. C.E., for the loan of the testing-machine and valuable assistance, and to Professor F. W. Burstall for many useful suggestions in the construction of the apparatus for carrying out the experiments.

The Paper is accompanied by ten drawings, from which the Figures in the text have been prepared; and by an Appendix containing a tabulated record of the results of the experiments.

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OBITUARY.

JOHN BRUNTON, born in Birmingham in the year 1812, began his engineering career as a pupil in the works of Messrs. Harvey and Co. of the Hayle Foundry, Cornwall. On the expiration of his pupilage he was engaged for two years on the construction of a colliery railway in South Wales. He was next employed for several years under George and Robert Stephenson on the London and Birmingham Railway, and on the Manchester and Leeds Railway. After a brief period of work on the Maryport and Carlisle line, Mr. Brunton practised on his own account in Scotland for four years. He then came south again and carried out work for Messrs. Hutchinson and Ritson, contractors, in connection with railways in Wiltshire, Somersetshire and Dorset. During the Crimean War he was engaged under I. K. Brunel in the erection of army hospital buildings in Turkey, and in the provision of water-supply and landing-piers for them.

In 1857 Mr. Brunton was appointed Chief Resident Engineer on the Scinde Railway. The line to be constructed was from Karachi to Kotri, a distance of 108 miles, and the work was commenced in April, 1858, and completed in 1862. In the following year Mr. Brunton presented to the Institution an account of the construction of the line,[1] for which he was awarded a Telford Medal and Premium. His next work was the survey of the Indus Valley Railway, on the completion of which, in 1866, he returned to England.

In 1870 Mr. Brunton took an office in Westminster, where he practised for twenty years. During that time he acted as engineer to some slate quarries in Wales and carried out various tramway and other works. The last years of his life were spent in retirement at Leamington, where he died on the 7th April, 1899, at the age of 86. Mr. Brunton during his residence in London frequently attended the meetings of the Institution. He was elected an Associate on the 3rd February, 1857, and was transferred to the class of Members on the 21st April of the same year.

[1] Minutes of Proceedings Inst. C.E., vol. xxii. p. 451.

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JOSEPH HARRISON, born at the important manufacturing village of Swalwell, near Newcastle-on-Tyne, on the 7th of January, 1826, was the second son of Mr. Edward Harrison, a farmer, and both father and mother were natives of Durham County. He served his apprenticeship with Mr. James Grey, a colliery viewer of local celebrity, at Marley Hill colliery, four miles from Newcastle, and on the completion of his term was engaged at the Stublock colliery, a pit somewhat remarkable, as from it were drawn coal, ironstone and lead—a very unusual combination. He was also for a time at Urpeth colliery in order to obtain a knowledge of the best methods of ventilating fiery coal-pits, under Mr. Edward Boyd, who was viewer-in-chief at that colliery. In 1848 he entered the service of Mr. William Cowen, contractor, and was placed in charge of the works of a railway from Haltwhistle to Alston, on which he acquired a practical knowledge of railway and bridge work.

When the late Robert Stephenson received instructions from His Highness Abbas Pasha, the then Viceroy of Egypt, in the year 1851 to lay out a railway from Alexandria to Cairo, a large staff of assistants was sent by him to survey the line and to superintend its construction, and Mr. Harrison was one of those selected, at the recommendation of Mr. George Robert Stephenson, the chief of the staff being Mr. Henry J. Rouse. The Egyptian Railway occupied some years in construction, and soon after its completion it was found that the large steam ferry which conveyed the trains across the River Nile at Kafr Zayat, on the Rosetta Branch, about midway between Alexandria and Cairo, was unable to cope with the increase of traffic which developed very rapidly after the opening of the line. It was therefore decided in 1856 to construct a bridge with a double swing opening across the river near the site of the steam ferry and thus to overcome the difficulties and avoid the loss of time caused by the conveyance of the trains by ferry. Mr. Stephenson had at this time, on the death of the Viceroy Abbas, retired from his position as consulting engineer of the railway, and Mr. George Robert Stephenson, who had already, under his cousin, designed swing-bridges for the railway at Benha and Birket-el-Saba, now submitted to the Viceroy, His Highness Saïd Pasha, a competitive design for the new bridge which was approved. The contract for its construction was let to Mr. Price, who had laid the permanent way of the main line, and Mr. Harrison was specially appointed to

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superintend the work under Mr. Rouse, who, after Mr. Robert Stephenson's retirement, had taken service directly under the Viceroy.

On the completion of the bridge towards the end of 1859, Mr. Harrison returned to England, and soon afterwards obtained the appointment of Engineer-in-chief of the Scinde, Punjab and Delhi Railway, Mr. G. P. Bidder being Consulting Engineer. Mr. Harrison held that appointment for fifteen years, and during that time carried out works of great magnitude and difficulty. He was highly esteemed and thoroughly trusted by the company, and at a time when the office of General Agent became vacant they indicated their confidence by proposing that he should accept that important post. Thus for some years he carried on successfully the responsible work of General Manager of the railway in addition to the heavy duties of Engineer-in-chief. Finding his health failing after fifteen years of service in a trying climate he resigned his position in 1875, and returning to England retired from further practice of the profession. Privately Mr. Harrison was universally liked for his generous character and for his kind and genial disposition. He was a keen sportsman and an excellent shot, and nearly to the end of his life he had no greater enjoyments than those afforded by the shooting season. His death took place at the Hôtel des Anglais, Mentone, after a rather long illness arising from heart disease, on the 24th February, 1899, in his 74th year.

He was elected an Associate on the 7th April, 1857, and was transferred to the class of Members on the 12th April, 1864.

JEREMIAH HEAD, born in 1835 at Ipswich, was a son of the late Mr. Jeremiah Head, J.P., who belonged to a Quaker family well known in that neighbourhood. He received his first instruction at home, and subsequently went to a private school at Ipswich, and afterwards to the Friends' School at Tulketh Hall, Lancashire. At an early age he was articled to Robert Stephenson, and served his time at the well-known locomotive and marine engineering works at Newcastle-on-Tyne, subsequently being promoted to a position on the civil engineering staff. In 1856 he was entrusted with the design and superintendence of the construction of a large pair of condensing engines, for driving the Priestgate Woollen Mills at Darlington, belonging to the firm of Henry Pease and Co. These engines were fitted with a para-

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bolic governor, controlled by an air cataract, and comprised several other details, specially designed by Mr. Head. In the following year he designed and superintended the building and erection of another pair of engines of somewhat similar character for the paper mills of Messrs. Anandale and Co., of Shotley Bridge, near Durham.

A little later he was appointed resident engineer for the re-building of the iron bridge over the Wear at Sunderland, which occupied two years, and was Stephenson's last public work of magnitude. He was then selected to co-operate with the late Mr. John Fowler in bringing to perfection the steam plough, with which that gentleman's name is associated, and in commencing the extensive works at Leeds, which became the principal seat of its manufacture. The set of steam ploughing apparatus, which succeeded in gaining the prize of £500, offered by the Royal Agricultural Society, and was exhibited at the Chester Show in 1858, was mainly constructed at the Newcastle Works, to the designs and under the supervision of Mr. Head. He also devised and patented a system of lamp signals, whereby steam ploughing operations might be carried on at night.

In the year 1863, in conjunction with Mr. Theodore Fox, J.P., Mr. Head built large ironworks at Middlesbrough, known as the Newport Rolling Mills, which he carried on until 1885. For several years an industrial partnership existed between the employers and the men at those works.

Mr. Head was one of those who advocated the establishment of the School Board system at Middlesbrough, and he sat on the first board, Middlesbrough being the first town in England to apply for a School Board on the passing of the Act. In 1864 he originated the Cleveland Institution of Engineers, which has contributed greatly to the success of the iron and steel industries at Middlesbrough. He occupied the position of Honorary Secretary for three years and of President for three years.

Since 1885, although still deeply interested in the Cleveland iron and steel industries, Mr. Head devoted his time and energies almost exclusively to consulting engineering. He designed and supervised the carrying out of several iron and steel works plants; made numerous investigations, sometimes under an order of court, sometimes at the instance of private owners, as to properties in litigation, or otherwise in difficulties.

Of late years he paid frequent visits to the United States, where he had much professional work. He made exhaustive reports on various properties, more especially iron, coal and manganese

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mines, and iron and steel works, for English and foreign clients. He was frequently retained as technical expert in law and arbitration cases connected with mechanical engineering and metallurgy, and still more often as sole arbitrator. He was frequently agreed to on both sides as referee on wages questions between large employers and their workmen, and he always succeeded in arriving at decisions which secured the respect of both parties. As a valuer of technical and other properties, Mr. Head had large experience, the aggregate amount which passed through his hands in this way reaching several millions during the last few years.

Mr. Head contributed several Papers to the British Association, the Federated Institution of Mining Engineers, the Institution of Mechanical Engineers, the Iron and Steel Institute, the Cleveland Institution of Engineers, the Sheffield Technical School, and various other societies, as well as numerous articles to the current technical literature of the day. Among his more recent contributions may be mentioned: "English and American Methods of Manufacturing Steel Plates,"[1] before this Institution in May 1896, for which he was awarded a Watt Medal and a Telford Premium; his joint Paper with his son, Mr. A. P. Head, on "Lake Superior Iron Ore Mines," before the same body in February, 1899; "Cleveland Industries" before the Institution of Mechanical Engineers in August 1893; and "Mechanical Science as exemplified in Nature," being a presidential address before the British Association, Section G, September 1893.

In 1885, having long been a member of Council, he was elected to the Presidential Chair of the Institution of Mechanical Engineers, and held that position for two years. In 1894 at the Nottingham Meeting, he presided over Section G, Mechanical Science, of the British Association for the Advancement of Science. He was one of the original members of the Iron and Steel Institute, the Treasurer and a member of the Board of Management of the British Iron Trades Association, and a member of the Board of Conciliation and Arbitration of the North of England Manufactured Iron Trades. He was a member of Council of the Federated Institution of Mining Engineers.

Since January, 1894, Mr. Head had been practising in Victoria Street, Westminster, in partnership with his son, Mr. A. P. Head.

Mr. Head died at Hastings on the 10th March, 1899, in his sixty-fourth year. His career was distinguished by great energy

[1] Minutes of Proceedings Inst. C.E., vol. cxxvi. p. 132.

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and untiring zeal, and he acquired valuable knowledge and extensive experience of mechanical engineering and metallurgical practice. The industrial partnership above referred to greatly assisted to introduce the system of co-operation into the Middlesbrough district, and the iron industry of Cleveland owes much to his example and influence. Mr. Head was elected a Member of this Institution on the 2nd March, 1875.

WILLIAM HENDERSON, son of the late Mr. James Henderson, of Glasgow, engineer and architect, was born on the 24th January, 1854. After serving a pupilage with his father he was articled to Messrs. Smith and Wharrie, engineers and surveyors, of Glasgow. He was then engaged for five years, from 1874 until 1879, as an assistant to Mr. James Wilson, who at that time was engineer to the Water Trust of Greenock.

In November, 1879, Mr. Henderson started in practice on his own account in Glasgow, and during the seven years following he designed and carried out waterworks for Dalbeattie, Annan, Stranraer, Maybole and Kilmarnock, and drainage works for Dalbeattie. He also assisted Mr. James M. Gale and Mr. James Wilson in connection with extensions of the Loch Katrine works for the water-supply of Glasgow, waterworks for Dumfries, Aberdeen, Ayr and Girvan, and other works.

Mr. Henderson's connection with the Colony of Victoria commenced in the year 1886, when he was engaged in making reports and estimates for irrigation projects under the instructions of the Royal Commission on Water-Supply. He was then appointed executive engineer to the Victorian Water-Supply Department, in which capacity he designed and superintended the construction of national irrigation works in the district of Goulburn. He was also engaged in preparing a report and estimates for a supply of water for domestic and stock purposes over about 17,000 square miles in the Mallee District. He retired from the service of the Victorian Water-Supply Department in 1895, and started to practise on his own account as a hydraulic engineer.

Mr. Henderson was an indefatigable worker, and to the unsparing energy he displayed in the performance of his duties may be attributed perhaps the early close of his career. About the end of 1897 he was stricken with paralysis, from which he made a partial recovery, but in the following autumn a relapse

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took place, and he died at his brother's residence, Bracken Lodge, Wannaene, near Dromana, on the 11th December, 1898, at the age of 44. Mr. Henderson was elected an Associate on the 5th May, 1885, and was transferred to the class of Members on the 16th November, 1896.

JAMES BERNARD HUNTER was the fifth son of the late Mr. James Hunter, of the firm of Messrs. Hunter and English, engineers, Bow, and was born at No. 1 Tredegar Place, Bow Road, on the 21st October, 1855. After being educated at King's College School, London, he was apprenticed to his father in 1872, and after passing through the usual course of instruction at the Bow Works, he proceeded to the Great Eastern Railway workshops at Stratford as a pupil of Mr. William Adams, then locomotive superintendent to that Company. He followed Mr. Adams when the latter became locomotive superintendent at the London and South Western Railway Works, Nine Elms. After some three years' valuable experience under Mr. Adams, he returned to Bow in 1880 as Works Manager to Messrs. Hunter and English, and in 1883 he, on the death of his father, became a partner in the firm.

For the past twenty years Mr. Bernard Hunter was prominently associated with all the work carried out by the firm, of which he ultimately became senior partner. He worthily maintained the reputation that firm has long enjoyed, by his abilities as an engineer, his skill as an organiser, and the high qualities of character which endeared him to a large circle of friends. His death took place at his residence, 13 Elsworthy Road, N.W., on the 21st April, 1899.

As a Student of the Institution, Mr. Hunter was awarded a Miller Prize in 1881 for a Paper on "Wood-working Machinery as applied to the Manufacture of Railway Carriages and Wagons."[1] He was elected an Associate on the 6th December, 1881, and was transferred to the class of Members on the 15th January, 1889.

JOHN JACKSON, youngest son of the late Sir William Jackson, Bart., was born on the 9th September, 1843. After serving a pupilage of five years to the late Mr. John T. Woodhouse, of Derby,

[1] Minutes of Proceedings Inst. C.E., vol. lxvi. p. 313.

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well known in that district as a mining engineer, he took charge, in 1866, of the extensive works and mines of the Clay Cross Coal and Iron Company, near Chesterfield, of which his father was the proprietor, jointly with Sir Morton Peto and Sir Joshua Walmsley. These works are interesting as having been founded by George Stephenson at the time he was engaged in constructing the Midland Railway in the neighbourhood of Chesterfield.

During the thirty-three years Mr. Jackson held that important post he was regarded as a model employer of labour, always willing to hear representations as to complaints, and ready, when circumstances justified him, to redress grievances. In the memorable struggle of 1893, he was one of the employers who, with representatives of the miners, sat at the "Round Table Conference," with Lord Rosebery in the chair. Mr. Jackson was a Justice of the Peace for the county of Derbyshire, and when his health permitted, was regular in his attendance at the Petty Sessions at Alfreton and Clay Cross. He took a deep interest in the affairs of the important mining centre, near which he lived, and indeed, in most of the public movements of the district and county. When the proposal was made to perpetuate the memory of George Stephenson by erecting a Memorial Hall in Chesterfield, where Stephenson lived and died, he gave his hearty support to the project, and became one of the guarantors. Lately the Hall passed by purchase into the hands of the Chesterfield Corporation. Mr. Jackson associated himself with the Chesterfield Institution of Mining and Mechanical Engineers, of which he was one of the most active members and at one time President. Personally, he was of a quiet kindly disposition, liked by everybody with whom he was associated. Through his thoughtfulness and consideration the affairs of the Company, so far as the relations between employers and employed were concerned, worked very smoothly, and the Clay Cross Company escaped much unpleasant friction by reason of his tact and kindness.

Mr. Jackson was in feeble health for some time before his death, which took place at Falmouth on the 28th February, 1899. He was elected an Associate of the Institution on the 3rd February, 1874, and was transferred to the class of Members on the 4th November, 1879.

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JOHN MARTIN McCURRICH was born at Dunning, Perthshire, on the 5th November, 1852. He was educated at Dunning, at the Dollar Academy, where he was the medallist of his year, and at Edinburgh University, where he graduated M.A. He then entered the office of Messrs. R. B. Bell and D. Miller, of Glasgow and Westminster, in 1875, for a term of three years, and after the expiration of his pupilage remained as an assistant until 1883. While there he was engaged on a great variety of work, including the Clyde Navigation Graving Dock, Grangemouth Waterworks, an iron and stone bridge over the River Kelvin at Glasgow, and the survey, tidal readings and observations for the navigation of the River Cart, a work which has since been carried out.

In April, 1883, Mr. McCurrich was appointed Resident Engineer in charge during the construction of the No. 2 Mount Stuart Graving Dock at Cardiff, which was constructed, from designs by Mr. Peter Whyte, without a contractor, and included a large cofferdam, two pairs of iron gates, sluices, &c., besides a large amount of masonry and concrete work. On the completion of the dock in August, 1884, he was appointed an assistant to Mr. John Wilson, Engineer-in-Chief of the Great Eastern Railway, where, in addition to designing and superintending the construction of dock, roof, and bridge works, he was engaged on hydraulic work, in connection with which he inspected and reported on the hydraulic appliances at several of the chief railway goods stations in England and Scotland.

In June, 1885, Mr. McCurrich entered the service of the Docks Committee of the Port of Bristol, as an assistant to Mr. J. W. Girdlestone. For nearly four years he had charge of the drawing office, and under the direction of Mr. Girdlestone he was responsible for the design and carrying out of new works. In February, 1889, he was appointed Chief Assistant, and, on the resignation of Mr. Girdlestone in November, 1890, he succeeded to the position of Docks Engineer. During the period which followed he was engaged on a great number and variety of works, among which may be mentioned a large grain warehouse, with grain elevating and conveying machinery; extensive transit warehouses at Bristol and Avonmouth, with hydraulic cranes, capstans, &c.; a new deep-water wharf wall; the widening and deepening of a bridgeway connecting two portions of the floating harbour, including cofferdams, &c.; new workshops, locomotive sheds and offices; a pumping station; two hydraulic engine-houses, with four sets of compound pumping-engines, boilers, accumulators, mains, &c.; ex-

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tensive cattle lairs, slaughter-houses and refrigerators; new culverts and large hydraulic sluices for the relief of floods and the scouring of Cumberland Basin; a floating dock, gridiron and slip for repairs of vessels; and many important works, including extensive port and river improvements for enabling vessels of increased tonnage to reach the City docks. A considerable proportion of these works was done without a contractor; so that he became thoroughly familiar with the details of the work, and with the value of materials and labour. He was also engaged on the drawings, specifications, quantities, &c., for a coaling dock and graving dock at Avonmouth, and for a large bascule bridge at Bristol, and on the Parliamentary and other drawings for new railways in connection with the docks (Session 1890). He had likewise considerable experience in dredging operations, the removing of rocks and shoals in the river, and the construction and maintenance of the necessary dredging plant. A recent work of interest was adapting the entrance lock of Avonmouth Dock for vessels of greater length by inserting a new sill, and the construction of a movable caisson.

Mr. McCurrich's most engrossing work was, perhaps, in connection with the several schemes for new docks at Avonmouth and Portishead, and for the dockization of the River Avon, which have been put before the Docks Committee of the Council. The preparation of plans and reports relating to this matter involved an immense amount of work and anxiety. Mr. McCurrich was exceedingly conscientious and painstaking, and most devoted in the performance of the duties attached to his post. The illness which came upon him while engaged in the consideration of these important schemes, on the results of which many influential citizens consider the future of the Port of Bristol to depend, ended fatally on the 18th January, 1899.

Mr. McCurrich was a man of sound common sense, well read, and of great good nature and modesty. He was beloved by his immediate subordinates and held in high regard by the large number of men employed under his direction. He was not only a most capable engineer, but was gifted with a clear, sound judgment, which rendered his advice very reliable and gained for him the confidence of the Docks Committee, and indeed, of all with whom he came in contact. Mr. McCurrich was elected an Associate Member of the Institution on the 1st December, 1885, and was transferred to the class of Members on the 22nd November, 1892.

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WILLIAM MORTON was born at Louth on the 4th October, 1832, and was educated at the Grammar School in that town. In 1850 he was a pupil to the late Mr. Henry Fowler, and was engaged on the construction of the East Lincolnshire Railway, the survey of the town and port of Great Grimsby, and the construction and repair of works on the Great Northern Railway. In 1855 he joined the staff of the late Sir John Fowler, Bart. (then Mr. Fowler), and during 1858–9 he acted as Resident Engineer on the construction of works in connection with the reclamation and enclosure of land at the estuaries of the Nene and Ouse in the counties of Lincolnshire and Norfolk. In 1859 he went to Portugal and laid out and superintended the Great North of Portugal Railway from Santarem to Oporto. Between 1859 and 1869 he was Chief Resident Engineer on the construction of the Metropolitan Railway from Bishop's Road to Farringdon Street, the Finsbury extension to Moorgate Street, and the western extension to South Kensington.

From 1870 to 1874 Mr. Morton carried out the construction of the Liverpool Central Station Railway under Sir John Fowler and Mr. W. M. Brydone. From 1874 to 1880 he was employed, under Mr. Brydone, in constructing the Liverpool North Extension Railway and terminus for the Cheshire Lines Committee, and during that time he was engaged on various parliamentary work in connection with the Mersey Tunnel and underground railways in and about Liverpool.

In 1882 Mr. Morton came to London and practised as a consulting engineer, but he devoted no little time also to Art, as from early days he was proficient as a painter in oils. Owing to ill-health he was obliged to retire in 1890. He died at his residence, 98 Oxford Gardens, W., on the 5th April, 1899.

Mr. Morton was elected a Member of the Institution on the 4th December, 1877.

HENRY DAVID ALEXANDER REID, born at Hamilton, Ontario, Canada, on the 11th May, 1856, was the eldest son of Mr. George Lowe Reid, at that time the chief engineer of the Great Western Railway of Canada. He was educated at St. Andrews, N.B., and subsequently at King's College, London, where he completed the engineering course in 1875, with considerable distinction, gaining five prizes, viz., for mathematics, chemistry, geology, surveying, and arts of construction. He was then articled

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for three years from 1875, as a pupil of the late Mr. Robert Hodgson, of Newcastle, at that time Chief Resident Engineer of the North Eastern Railway. In October, 1878, he was engaged by the late Mr. David Reid, the contractor for the Kandy and Matalé Railway, Ceylon, to take charge of the construction of a section of that line, Mr. J. R. Mosse, being the Chief Resident Engineer, under the late Sir Charles Hutton Gregory. The works were completed in the beginning of 1881.

In November, 1881, Mr. Reid assumed charge of the construction of a section of the Jamaica Government Railway, between Spanish Town and Ewarton for the contractors, Messrs. Reid and Mackay, the Chief Resident Engineer being Mr. Valentine G. Bell, Director of Public Works, Jamaica. A special feature of this railway was the construction of all its bridges and viaducts in Portland cement concrete, as no durable building stone was to be found in that district. Mr. Reid returned to England on the completion of the Railway in June, 1886, and in the following December he was sent to Venezuela by Mr. James Livesey, to make the surveys for the South Western of Venezuela (Barquisimeto) Railway, and was afterwards appointed Chief Resident Engineer for the construction of the line extending from the Quebrada Copper Mines to Barquisimeto. He returned to England in November, 1889, and entered the office of Mr. Livesey as chief assistant. In April, 1891, he sailed for Peru, having been appointed by Mr. Livesey to the post of Chief Resident Engineer of the railways of Peru, belonging to the Peruvian Corporation of London. Having completed the summit section of the Great Central Railway from Callao to Chicla to the satisfaction of the Peruvian Government, he returned to England in October, 1893.

In February, 1894, Mr. Reid was appointed engineer and general manager of the Arica and Tacna Railway in the Northern Province of Chile, a post which he held for five years, during which period he brought the company out of a state of financial difficulty into a dividend-paying condition.

He also made a reconnaissance of the proposed extension to La Paz in Bolivia, a distance of 284 miles, for which the railway company possesses a concession, and made a report and approximate estimate of the cost of that extension which met with the approval of the London Board of Directors. Having completed his engagement with the Arica and Tacna Railway Company in February, 1899, Mr. Reid accepted the appointment of general manager and engineer of the Anglo-Chilian Nitrate and Railway Company of Tocopilla, Chile. He spent a week or so in making an inspection

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of the nitrate works and railway, and, as arranged with the London Board of Directors, set out on a visit of three months to England, travelling overland from Valparaiso to Buenos Ayres. In crossing the Summit Pass of the Andes, he caught a severe chill, which, after he had sailed from Buenos Ayres, developed into pneumonia, and proved fatal on the 20th March, 1899, when he was within six days of Southampton.

Mr. Reid was an able engineer, both theoretically and practically, and a man of excellent business capacity, tact, and sound judgment. Of the strictest integrity and unbending principle, he was highly esteemed and thoroughly trusted by his several employers and Boards of Directors, whilst his generous and kindly disposition endeared him to a wide circle of friends and to all the men under his control, whose advancement in life he had ever at heart. He has left a widow and four young children.

Mr. Reid was elected an Associate Member on the 6th December, 1881, and was transferred to the class of Members on the 21st March, 1893.

THOMAS GIBSON BARLOW-MASSICKS, son of Mr. Thomas Barlow-Massicks, formerly Managing Director of the Millom and Askam Hematite Iron Company, and now Chairman and Managing Director of the Lonsdale Iron Company, Whitehaven, was born on the 12th June, 1862. His engineering career began in 1883, when he joined the firm of Messrs. John E. Swan and Brothers, metal brokers, of Middlesbrough. Three years later he was invited by the directors of the Vulcan Steel and Forge Company to re-organize their works, a task which he carried out to their satisfaction, and in 1889 he assisted in the management of the works of the Cumberland Iron Mining and Smelting Company.

In 1890 Mr. Barlow-Massicks was engaged by the Lynx Creek Gold and Land Company as resident engineer and managing director of their works at Prescott, Arizona, U.S.A. In that capacity he laid out, jointly with Mr. W. Everard Pedley, extensive hydraulic works, and surveyed and mapped out the large properties owned by the company. Unfortunately, however, his career was cut short prematurely. In the spring of 1898 he was seriously injured by the accidental discharge of his revolver. The bullet, which had passed upwards through the left lung, could not be extracted, but there were hopes of ultimate recovery. Those hopes, however, were not realized, death taking place at the Mercy Hospital, Prescott, on the 13th April, 1899.

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Mr. Barlow-Massicks had considerable inventive faculty, and took out patents for, among other things, an improved system of wagon coupling, a carriage brake, a spiral elevator, and a gold-washing machine for dealing with alluvial deposits. He was elected an Associate Member on the 5th December, 1893.

SAMUEL COOKE, son of the Rev. John Cooke, of Tramore, Waterford, was born at Waterford on the 22nd May, 1844. He was educated at Dublin University, where he graduated in Arts and obtained the first place in the examination for the engineering diploma granted by that University. In August, 1868, he was appointed by the Secretary of State for India Professor of Chemistry and Geology in the Civil Engineering College at Poona, now known as the College of Science. Professor Cooke held that post for the remainder of his life, and, in addition to its duties, acted from time to time as Principal of the College, being formally appointed to the latter office in 1893. He was a Fellow of the University of Bombay, and in 1896 was elected Dean in Civil Engineering. He was also a Fellow of the Geological Society, of the Royal Astronomical Society and of the Institute of Chemistry, and a Corresponding Member of the Royal Historical Society of Great Britain.

Professor Cooke died at Clifton on the 26th February, 1899. In addition to his scholastic duties, he was the author of several works, among which may be mentioned "First Principles of Chemistry," "Students' Practical Chemistry," "First Principles of Astronomy," "Forests and Rab in India," and "The Foundations of Scientific Agriculture." He was elected an Associate of the Institution on the 5th December, 1876, and was subsequently placed in the class of Associate Members.

HENRY ADAIR GOVETT ORR was the third son of the late Mr. Henry A. Orr, of Pemberly, Victoria, where he was born on the 28th June, 1856. Coming to England, he was educated at the Bedford Grammar School, and served an apprenticeship at the locomotive works of the London and North-Western Railway Company at Crewe, where he was subsequently employed. In 1881 he went to Australia. Soon after his arrival in Melbourne he

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was engaged by the Queensland Government to take two steam-ploughing engines and tackle some 700 miles up country to be employed for making reservoirs for conserving the water in dry districts. The heavy work of getting these engines over rough country, through loose sand and muddy creeks, served to bring out the qualities of ready resource and indomitable will which characterized Mr. Orr throughout his life. Returning to Melbourne in 1884, he joined in partnership with Messrs. Hodgson and Bernard-Smith. Together they carried out several engineering works for the Victorian Government, among which may be mentioned the design and erection of a large water-tower at Numurkah on the Murray River for the supply of several neighbouring towns.

In 1890 Mr. Orr was called to England on account of family matters, and finding that these entailed the abandonment of his Australian career, he settled at Bedford. His worth of character was recognized among others by Lord Ebury, of Moor Park, Hertfordshire, who recently offered to him the agency of his estate, and Mr. Orr had taken up these new duties with marked promise of success. Unfortunately a neglected attack of influenza developed into a serious illness, which ended fatally at his home, Pemberly Cottage, Bedford, on the 22nd February, 1899.

Though never demonstrative, Mr. Orr was greatly loved by those who were privileged to be his friends, as well as by the members of his family circle. A man every inch of him and excelling in all manly sports, he lived a blameless life. No unkind word of others passed his lips. Insincerity in any form was a stranger to him. Reserved as to his religious convictions, it was only his most intimate friends who knew that his strength was drawn from the true source.

He was elected an Associate Member of the Institution on the 3rd December, 1889.

ALFRED LINDLEY PEACE was born on the 18th September, 1837, at Huddersfield, where he was educated. After serving articles to Mr. R. Shaw, Civil Engineer, of that town, he entered in 1857 the office of Mr. Makin Durham, of Thorne, near Doncaster, to whom he in course of time became Managing Assistant. On the death of Mr. Durham, in 1882, he was appointed Manager to the Durham Trustees, and, in fact, succeeded to that gentleman's practice. Mr. Peace acted as Engineer to the Hatfield Chase Level authorities, the Trustees of the River Went, the Reedness and

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Swinefleet Drainage Commission, and the Selby Dam Drainage Commission; and as Secretary to the Hatfield Chase Warping and Improvement Company. In addition to those appointments he had a considerable private practice. During the forty years of his residence in Thorne, Mr. Peace filled numerous public offices, being Chairman of the School Board, Churchwarden, a Guardian of the Poor, and a Member of the District Council. He was an active Freemason. Mr. Peace died at Thorne on the 26th November, 1898. He was elected an Associate Member on the 2nd February, 1886.

JAMES WALLACE PEGGS, born in London on the 3rd September, 1848, was educated at King's College School. In 1865 he was articled to Mr. J. W. Grover, and in 1867 and 1868 he was employed as resident engineer on the construction of the Clevedon Pier. He was engaged in the same capacity in 1869 and 1870 on the new pier at the Royal Arsenal, Woolwich, and from 1870 to 1872 he designed and carried out a dock and sea-wall at Garston, near Liverpool, for Hamilton's Windsor Ironworks Company. From about 1884 to 1887 Mr. Peggs acted as engineer to the Metropolitan Asylums Board, and carried out amongst other works an ambulance station and pier at Fulham, dry earthworks near Longreach, and various matters in connection with the Board's fleet of hospital ships and ambulance boats. About this period he carried out various works for the Guardians of the Poor of the Parish of St. Leonard, Shoreditch.

In 1888 Mr. Peggs was elected a Member of the Council of the Sanitary Institute, but owing to ill-health resigned his connection a few months previous to his death. He designed and presented to the Parkes Museum an interesting model showing the cone of depression produced in water-bearing strata caused by pumping from a deep well. He took great interest in experiments on the action of the wind on cowls, and was for many years one of the judges in connection with the annual exhibitions of the Sanitary Institute, in which capacity he took a deep interest and rendered much valuable service. Mr. Peggs died at his residence, Southbourne Lodge, Christchurch, Hants, on the 24th February, 1899.

He was elected an Associate of the Institution on the 4th February, 1873, and was subsequently placed in the class of Associate Members.

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JAMES FOLLIOTT STOKES,[1] youngest son of the late Mr. Charles Scott Stokes, of Beachley, Gloucestershire, was born on the 6th November, 1832. He began his engineering career as a pupil of Sir Charles Fox. The first railway on which he was engaged was the Great Northern, at first on the construction of the bridge which carries that line over the Ouse near Huntingdon, and then in erecting all the iron bridges, aqueducts, &c., on a length of about 50 miles from south of Hatfield to near Peterborough. On the Ouse Bridge some of the foundations were weighted to 7 tons per superficial foot at the suggestion of Field-Marshal Sir John Burgoyne. Subsequently Mr. Stokes was engaged in Derbyshire, and on the erection of buildings requiring foundations on land reclaimed from the sea in Portsmouth Dockyard. He had had some previous experience of that class of work at Pembroke Dockyard.

From 1853 to 1858 Mr. Stokes was employed principally on the Continent, at first having under his charge work in the south of Sweden and in the south of France, and then taking charge for some time of a length of 60 miles of the Lyons and Geneva Railway from a suburb of Lyons on the right bank of the Rhone to Ambérieux on the main line, and from there on the branch line to Macon. This length of line runs for some miles along the Rhone, and is carried twice across the Ain on two large ashlar bridges of magnesian limestone. It crosses the Saône near Macon. In 1854–55 a bridge just completed over the Saône at Lyons on the junction between the Paris and Lyons and the Lyons and Mediterranean lines having fallen, English engineers were asked to design a new bridge of two spans of 200 feet with one pier, to be sunk through the foundations of the old bridge, to be founded dry under a pressure due to a column of water of a minimum height of 50 feet. Of the construction of this design Mr. Stokes took charge, and remained in charge until the bridge was opened for passenger traffic, to the exclusion of almost any other work, except the commencement of a bridge over the same river for the Lyons and Geneva Railway. He was subsequently engaged for short periods in different ports of France, in Rhenish Prussia, and in Holland.

In 1862 Mr. Stokes returned to England, and with the exception of a short period in 1864 passed in Belgium and Holland studying the route of a proposed line from Malines to Terneuze, which

[1] This notice is mainly autobiographical.

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involved the construction of a road and bridge over the Scheldt, he was actively engaged in English railway work from 1863 to 1867. In 1868 he became connected with the Lahore and Peshawur Railway, on which he was employed for about three years. In 1871 and 1872 he was employed as an Executive Engineer on the Kharian Division of the Punjab Northern State Railway. In October, 1872, he was appointed Assistant Consulting Engineer to the Government of India for State Railways, and was engaged on various works in the Punjab and at Simla until 1878, when he returned to England. From that time Mr. Stokes retired gradually from active practice. He died at the Isle, near Shrewsbury, on the 6th January, 1899, at the age of 66. He was elected an Associate on the 6th December, 1859, and was subsequently placed in the class of Associate Members.

JOHN WHITE, son of Mr. Nicholson White, of Folkestone, was born on the 11th August, 1867. After serving articles to the late Mr. A. W. Conquest, Borough Engineer of Folkestone, he was appointed Assistant Borough Engineer in May, 1889, and was entrusted with the supervision of important drainage and outfall works at Sandgate. On the death of Mr. Conquest he was elected, in May, 1892, Engineer and Surveyor to the Borough of Folkestone. In that capacity he designed and constructed a sea-wall, promenade and gardens on the sea-front, and, under the advice of Mr. James Mansergh, divided the outfall sewers into high- and low-level systems. His last work was an extension of the Sanatorium, formally opened only one week before his death, which took place on the 22nd October, 1898, from typhoid and peritonitis. Mr. White was a man of most amiable disposition and was much esteemed by all with whom he came in contact. He was elected an Associate Member on the 7th February, 1893.

SAMUEL BAYLISS was born on the 27th October, 1821, and, on leaving school, was articled to Mr. Richard Prosser, Civil Engineer, of Birmingham, with whom he remained for some years. About the year 1857 he proceeded to Egypt, where he was engaged on the construction of railways, including a bridge over the River Nile at Beimar. He then went to Brazil, where for nearly four years he was occupied as Resident Engineer on the Dom Pedro Segundo

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Railway. Subsequently he became identified with the Smyrna and Cassaba Railway in Asia Minor, and, after its completion, he projected and carried out an extension of that railway to Alascheir.

Mr. Bayliss had other important matters in hand in Turkey, but the breaking out of the Russo-Turkish War in 1877 prevented their being carried out, and he then retired from active life, having on his retirement received from the Sultan of Turkey the Order of the Medjidieh for distinguished services to that country. He spent the remaining years of his life in England. Early last year his health began to fail, and he died on the 27th November, 1898, in his 78th year.

Mr. Bayliss was elected an Associate of the Institution on the 2nd February, 1864.

SAMUEL SWARBRICK, formerly General Manager of the Great Eastern Railway Company, died at The Cedars, Tottenham, on the 22nd January, 1899, at the age of 79. Born in 1819, Mr. Swarbrick entered in 1838 the service of the Manchester and Leeds Railway Company, now part of the Lancashire and Yorkshire Railway Company's system. There he rose to the post of Accountant, and in 1851 he was appointed to a similar office in the service of the Midland Railway Company. During the following fifteen years he assisted in promoting the great development of the Midland system which took place under the management of the late Sir James Allport.

In 1866 Mr. Swarbrick was appointed General Manager of the Great Eastern Railway Company, and during the fourteen years he held that post the position of the Company was greatly improved, the problem of a northern outlet was solved, and the present large suburban traffic was originated. Mr. Swarbrick resigned office in 1880, from which time he acted as an adviser in Railway matters. In 1882 he made, in conjunction with Sir James Allport, an exhaustive report on the New York, Pennsylvania and Ohio Railroad, and two years later he became a Director of the Hull and Barnsley Railway Company. During the last eight years he lived in retirement at Tottenham.

Mr. Swarbrick shared with the late Mr. George Parker Bidder the gift of rapid calculation and the facility of dealing with large masses of figures. He was elected an Associate of the Institution on the 3rd March, 1868.

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*** The following deaths have also been made known since the 14th February, 1899:—

Honorary Member.

GALTON, *Sir* DOUGLAS, K.C.B.; *died* 10 March, 1899.

Members.

BUTLER, RICHARD; *died* 25 March, 1899.
FOGGIN, WILLIAM; *died* August, 1898.
HYSLOP, PETER SHARP; *died* 12 February, 1899.
KITSON, JOHN HAWTHORN; *died* 21 May, 1899.
LIVESEY, FRANK; *died* 3 May, 1899.
LYSTER, GEORGE FOSBERY; *died* 11 May, 1899.
NORMAN, MATTHEW JAMES JOSEPH PATRICK; *died* 1899.
PAYNTER, LINDLEY WILLIAM; *died* 21 May, 1899.
RINECKER, FRANZ; *died* 10 April, 1899.
WAKEFIELD, HENRY; *died* 18 April, 1899.

Associate Members.

ACTON, WILLIAM RICHARD; *died* 14 April, 1899.
CLEMINSHAW, THOMAS STANLEY; *died* 18 March, 1899.
FOSTER, JOHN FRANCIS; *died* 16 March, 1899.
GOODFELLOW, CHARLES EDWARD; *died* 15 May, 1899.
HART, HENRY SEBASTIAN; *died* 12 April, 1899.
POTTS, JOSEPH; *died* 28 October, 1898.
PREW, EDWARD JOHN; *died* June, 1897.
ROBERTS, GRIFFITH; *died* 7 March, 1899.
WALLACE, JAMES DOUGLAS; *died* 31 March, 1898.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 27 May, 1899.

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Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

A New Graphical Method of Determining Areas.

Alfred E. Wiener.

(Mittheilungen aus der Praxis Dampfkessel- und Dampfmaschinen-Betriebes, 1898, pp. 476, 502.)

If x and y be the rectangular co-ordinates of the curve enclosing the area, the elementary area is $y\,dx$. In the Author's method an auxiliary curve is drawn, its relation to the original being expressed—

$$y\,dx = z\,dz,$$

and the total area is

$$A = \int_{z_2}^{z_1} z\,dz.$$

This represents the area enclosed between the axis, a line inclined 45° to the axis, and the two end ordinates z_1 and z_2.

The practical application of the method is developed as follows: The area to be measured has a horizontal line, drawn in any convenient position, and a vertical line, dividing the area approximately into two equal parts as near as can be estimated by eye. A number of vertical ordinates are drawn from the points 0, 1, 2, . . . on the horizontal line, their distance apart being taken small where their height varies rapidly, but greater where their height remains constant or varies regularly. Along the horizontal line the distances 0′0, 1′1, 2′2, . . . are set off equal to the intercepts by the corresponding ordinates. With 0′ as centre a circular arc is drawn from the point 0 to a point midway between the ordinates 0 and 1; from this point a circular arc is drawn with the point 1′ as centre to a point midway between the ordinates 1 and 2. The process is continued until the end ordinate z_2 is reached. Similarly the process is continued to the left until the end ordinate z_1 is reached; z_1 and z_2 form the sides of a right-angle triangle, whose diagonal is equal to the diagonal M K of a square equal in area to the given figure.

In using the method it is not necessary to actually draw all the lines shown in the diagram given. The probable error due to inaccuracy in using the method is discussed, and the conclusion is drawn that the error will be in most cases probably less than by the method of adding ordinates. A. S.

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An Instrument for taking Compass Bearings by Night.

EMIL MÜLLER.

(Mittheilungen aus dem Gebiete des Seewesens, 1898, p. 997.)

During daylight the instruments in use for taking compass-bearings fulfil requirements, but by night, when the marks sighted are but faintly visible, results cannot be obtained quickly enough, as, when sighting, the compass light must be covered, and must again be brought into use to read the result. To avoid this difficulty the Author constructed the instrument to be described, which he found satisfactory in practical use.

The instrument is simple, and consists of an oblong brass box, equal in length to the diameter of a standard compass, on the top of which it is placed. It turns upon a screw in the centre of the compass, which fits into the bottom of the box in the centre of its length. A light is placed on one side, opposite the pivot. Outside, on the top of the box, a foresight is fixed, which is lit up through a narrow slit in the lid. The aftersight is a bright circle with a downward point, made by cutting a suitable hole in a small raised dome on top of the box.

The compass card is visible through an opening in the bottom of the box, and fixed to the lid inside is a mirror inclined at an angle so as to show a reflection of the card when seen through a hole in the back of the box. The line of sight is drawn on the mirror, which also shields the opening in the back from direct light, so that the sights can be laid on a mark, and the bearing read off in the mirror simultaneously. Sketches of the instrument are given.

W. B.

Mine-Surveying in the Rocky Mountains. J. BARRELL.

(Mines and Minerals, vol. xix., 1898, p. 241.)

The Author describes some rapid methods of plumbing vertical shafts, and of surveying inclined shafts, especially suited to mines in highly-inclined fissure veins. Incidentally he notes that two methods are in use for illuminating the backsight. In the first a thin board, 3 or 4 inches square, has three holes cut in it to receive candles. The plumb-bob is lowered to within a few inches of the floor, the board set underneath it, two lighted candles placed in the front holes, and the illuminated string is seen between them. An unlighted candle is placed behind the plumb-bob in the third hole for a background. This device is very portable, but it is useless in windy places, or for long sights. In such case the second method is to be preferred. The apparatus consists of a galvanized iron pail with a hole punched in the lower side.

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The ragged edges turned inwards hold a candle in place. Small holes are punched in the lower part of the sides and in the top. A stout piece of greased paper is tied over the front, and the flattened lower side of the pail is nailed to a small board. To this board three light legs are fastened by leather hinges. A lighted candle is placed in the pail, and the dark string may be seen against the bright background for a great distance. For marking the survey stations brass tags, about 1¼ inch in diameter, are used. They have consecutive numbers stamped on them, and have three holes punched for nails. The upper two are larger than the lower one. The lower nail to which the plumb-line is attached should have a conical head. It should be about $\frac{3}{32}$ inch in diameter and 1¼ inch long. The tag is nailed to the lower edge on the side of a timber, or, in the case of a rock roof, to the side of a plug.

B. H. B.

Mine Survey Stations where the Roof is Poor.

C. M. HENRETTA.

(Mines and Minerals, vol. xix., 1898, p. 247.)

Where the roof of a mine is sound there is no difficulty in marking the survey stations, but where the roof is bad great trouble is often experienced. In the Ohio collieries it has been found advantageous to use the following method: Plugs made out of horseshoe nails flattened at the end, with a small hole punched in them, are put into the side. From three of these plugs a triangular piece of thin galvanized iron, 1½ inch long on each side, is suspended by three brass chains. In the centre of the triangular piece there is a small hole to admit a thin wire to which the plumb-line is attached. Each of the pieces of chain are 5 feet long, although in exceptional circumstances a greater length may be used. At the end of each chain is a small hook which fastens in the plug at the side of the roadway. The chains are put up, the plumb-bob suspended from the centrepiece, and the theodolite set upon under the point of the plumb-bob.

B. H. B.

Submarine Surveying. CHARLES BRIGHT, Assoc. M. Inst. C.E.

(Engineering, 13 January, 1899, p. 35.)

Steel wires are now taking the place of hemp lines for deep-sea soundings. The latter were frequently as much as 2½ inches in diameter, and a deep-sea sounding often occupied 12 hours. With a steel piano-wire of 0·03 inch diameter, the same operation can

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now be performed in less than an hour. Various kinds of sinkers are illustrated and described. Their object is to take the line to the bottom of the sea, and drive a tube sufficiently far into the material forming the bottom to enable a sample to be brought up. The sinker is then automatically detached, and left at the bottom. The weight of the sinker is from 50 lbs. to 75 lbs., the latter only being used at greater depths than 2,500 fathoms. The latest form is that designed by Mr. Edward Stallibrass. On striking the bottom, the tube which projects beyond the weight is driven into the ooze, while the impact brings a spring into action, which, through suitable mechanism, releases the weight the moment the wire is hauled taut from the ship. The tube which penetrates the bottom is 5 to 6 inches long, and the samples frequently show definite strata. The advantage of this method of releasing the weight is that the precise moment at which the wire becomes taut can be readily ascertained, and so the depth can be accurately measured. On lowering the weight, however, the moment of striking the bottom is not so easily observed. With the old form of detachers, which released the weight the moment the bottom was struck, the slack of the wire was carried from the verticals by currents, and on hauling in again the tube left the bottom before the wire had assumed a vertical position. These considerations tended to make the soundings inaccurate.

A. P. H.

The Testing of Natural Stones. M. Gary.

Mittheilungen aus den koniglichen technischen Versuchsanstalten zu Berlin, 1898, p. 243.)

This Paper gives in tabular form the results of all experiments made on natural stones at the Royal Testing Laboratory, Berlin, during the three official years 1895–96 to 1897–98, and forms a supplement to a former Paper.[1]

The preparation of the specimens for testing is now usually done in the laboratory, the number of diamond saws having been increased of late years. This allows of tests being made more quickly, and of better control as to identity of material, and the direction of the stress applied relative to the natural layers of the stone.

Slight improvements in the methods of carrying out tests have been made from time to time.

A. S.

[1] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 328.

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Belgian Limestone in Constructions.

D. E. C. KNUTTEL and H. VAN OORDT.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1898–99, p. 14.)

The supply of Belgian limestone for public works has of late years given many causes of complaint. The Authors were commissioned to report on the quarries from which this material was obtained. Three different qualities are principally distinguished, and known as the "Devonian," the "Petit Granit," and the Meuse stone. The Devonian is the older formation, the two others belonging to the coal measures, the Meuse stone being the uppermost in the strata. They are all a crystalline limestone, with many fossils, mostly blue-gray in colour, sometimes yellowish to nearly white. The different beds are divided by faults filled with black friable earth, and sometimes black veins are found in otherwise compact stone. To avoid failures of this kind thicknesses of more than 40 centimetres (16 inches) should be avoided for coping-stones or ornamental parts. For inside fillings, where not exposed to the air, and in rubble walls, these failures are of less importance. On the whole, this stone is a useful building material if from quarries that are properly worked and where no explosives are used. The resistance is from 600 kilograms to 800 kilograms per square centimetre, that of granite being 1,000 kilograms (14,223 lbs. per square inch). Its price at the quarries is from 80 francs to 100 francs per metre cube (2*s.* to 2*s.* 4*d.* per foot cube) for ordinary sizes or shapes. Several plans and sections illustrate the Paper, to which are also added several extracts from specifications containing directions with regard to this material.

H. S.

Physical and Electrical Properties of Metals and Alloys.

H. F. PARSHALL, M. Inst. C.E., and H. M. HOBART.

(Engineering, 30 December, 1898, p. 869.)

A Table is given presenting in compact form recent information previously scattered through various publications. Names of observers are given, but no attempt is made to reconcile divergent results. The following is an abstract :—

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Metal or Alloy.	Micro-ohms per Cubic Inch at 0° C.	Increase of Resistance per ° C.
		Per Cent.
Aluminium (commercial) 97·5 per cent. Al.	1·05	4·35
„ bronze 90 per cent. Cu, 10 per cent. Al.	4·96	0·105
Bessemer steel (soft), 0·045 per cent. C.	4·14	..
Copper (electrolytic, annealed)	0·614	0·428
„ (99·29 per cent. Cu, 0·71 per cent. Zn)	0·72	0·373
Gold (99·9 per cent. pure)	0·865	0·377
Iron (very pure)	3·57	0·625
„ (white cast)	22·3	..
„ (grey cast)	44·9	..
„ (wrought, annealed)	5·44	..
Mercury	37·1	0·072
Phosphor bronze (Cu, Zn and P)	0·63	0·394
Silver (pure electrolytic)	0·579	0·400
Zinc (very pure)	2·26	0·406

A. P. H.

The Elasticity of Cast-Iron subjected to repeated Tensile and Compressive Strains. KARL BERGER.

(Mittheilungen des k. k. Technologischen Gewerbe-Museums, 1899, p. 13.)

Hitherto there appear to have been but few recorded investigations into the behaviour, in respect to its elasticity, of one and the same material, subjected to repeated tensile and compressive strains. Reference is made to certain tests made by Professor Bach with cast-iron under these conditions, and the results obtained by him are set forth in a series of seven conclusions.

In the last of these it is asserted that the relative proportion between the tensile and the compressive elasticity in the case of cast-iron is strongly influenced by the extent to which the sample has been previously subjected to stress. In the tests made by the Author parallel samples were submitted to tensile and compressive strains in an Emery testing-machine, fitted with a mirror apparatus which enabled readings to be recorded to $\frac{1}{10,000}$ of a millimetre. The tensile test-rods were each 0·798 inch in diameter and 7·87 inches in length; the compression tests were made with pieces of the same rod 4·72 inches in length. The tests for tension were raised $\frac{1}{4}$ ton each time from $\frac{1}{4}$ ton up to 5 tons. In the case of each test the increase in elongation and the total elongation, as also the permanent elongation, were recorded and the compression tests were carried out in a similar way After each test the load was put back to $\frac{1}{4}$ ton; a return to zero not being needed. The results of the experiments are set forth in a series of eight tables. The generally accepted modulus

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of elasticity for cast-iron can, it is shown, be materially diminished by repeated exposures to tension. The Author sums up the results of his experiments in a series of nine conclusions, among which are the following:—that no regular value can be assigned for the elastic elongation due to a definite load as this elongation can be increased by previous tension. In respect of pure elasticity there is no definite proportion between the amount of load and the elongation. In cases of previously applied tension, the tests for compression show sensible increase in the degrees of compressibility, and previous tension induces a marked amount of additional elastic deformation under compression.

G. R. R.

Influence of Heat, Chemical Composition and Mechanical Treatment on the Strength of Copper. M. Rudeloff.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1898, p. 171.)

In 1894 Prof. A. Martens reported on a series of preliminary experiments on the strength of copper.[1] The objects of the principal experiments were to discuss—

(1) The influence of chemical composition.
(2) The relation between the chemical composition and mechanical working.
(3) The safe working stresses that might be used.
(4) The strength of riveted and brazed joints.
(5) The influence of heat.

The present series of experiments are directed to the subjects marked (5) above, and in a less degree to those marked (1) and (2).

Eight kinds of plates and three kinds of round bars were used for the experiments; of each kind hard-rolled and annealed specimens were obtained. The experiments were carried out at temperatures of − 80, − 20, + 20, 100, 200, 300, 400, 500, and 600° C. The methods of cutting the test specimens from the plates and bars and the methods of carrying out the experiments are described.

Results of the Experiments.—The extension per unit load is generally greater the higher the temperature. Plates and bars containing a high percentage of copper are in a special degree influenced by heat. With regard to the extension up to the yield-point at different temperatures, cold hammering and cold rolling seem to have the same effect.

The breaking strength and the yield-point become lower as the temperature is raised; the reduction up to 200–300° C. is comparatively small, but at higher temperatures the reduction proceeds

[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 474.

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more rapidly. At moderate temperatures mechanical working of the metal increases the breaking strength, but at higher temperatures this influence gets less and less, until at 400–500° C. it is insensible. The influence of heat on annealed copper is less than on cold rolled and cold hammered material.

Between the temperatures of − 80° C. and + 300° C. the greatest elongation after fracture occurs at temperature − 20° C. At temperatures higher than 300° C. the behaviour as regards extension after fracture is very different for the different materials, in some cases the elongation after fracture increasing, in others decreasing as the temperature increases.

The influence of the chemical composition of the materials, *i.e.*, the presence of foreign substances, is not clearly marked in these experiments.

The Paper is accompanied by numerous Tables and diagrams.

A. S.

Some Experiments on Bridges under Moving Train-Loads.

F. E. Turneaure, Assoc. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, November, 1898, p. 783.)

The instruments used were a Fraenkel deflectometer and extensometer. In the former the instrument is fastened to the bridge, and connection is made by a taut wire to a heavy weight on the ground directly underneath. A pencil connected to the wire marks on a revolving drum driven by clockwork the motion of the bridge magnified twofold.

The extensometer records the longitudinal distortion of a bridge, magnified about 140 times, by means of a compound lever on a strip of moving paper, as in the former case. The instrument is clamped to the bridge member, and a long, light rod connected to the short end of the lever system is clamped at its other end to the bridge member.

After a little experience it was concluded that the members from which the most significant curves could be obtained were the lower chord member, the main diagonal nearest the centre, and the hip-vertical. With spans of less than 50 feet the jar of the girder accorded so closely in period with that of the moving parts of the deflectometer—about twenty per second—that the apparatus was set in excessive vibration. In the extensometer the rate of vibration of the moving parts was about ten per second, and the same difficulty was not experienced. With train-speeds of less than 25 miles per hour little vibration was caused. The increase in deflection due to vibrations caused by locomotives running at speeds of 40 miles to 50 miles per hour was found to be 40 per cent. or 50 per cent. for girder spaces less than 50 feet, and 25 per cent. for 75 feet spans. Owing to cumulative effect the percentage

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was a maximum of 20 or 25 for spans from 75 feet to 150 feet. The relative increase in chord stress was about the same as in deflection, but in the centre diagonal was rather more. The effect of speed of application of the load appeared to be of no consequence in the spans tested.

A. W. B.

Alteration and Partial Reconstruction of the Elbing Bridge.

L. Dyrssen.

(Zeitschrift für Bauwesen, 1898, p. 27.)

The Dirschau to Königsberg railway crosses the River Elbing about 1¼ mile from the Elbing station, and is carried by a bridge of five spans, the distance between the abutments, including the four piers, being 239 feet 6 inches. The original bridge was constructed for a single line in 1853–1854, the main girders being of the small-meshed lattice type; it was later on widened for a second track on the southern, or up-stream side, the main girders being of the parallel-flanged Warren type with the two centre bays counter-braced.[1]

The increased traffic, the use of heavier engines and higher speeds, gradually made evident the necessity for a thorough renovation of the masonry, especially of the abutments, and the replacement of the lattice girders by others more suitable to the changed conditions, rather than their repair. The Warren girders of the up-stream half of the bridge were in good condition.

Another circumstance which made desirable an alteration in this bridge was the fact that the River Elbing has, since the construction of the first half, been rendered navigable, and the piers, which were erected at right angles to the centre line of the railway, constituted a serious obstruction, being at an angle to the stream. To remedy this, it was determined to include in the alterations the removal of the second pier from the western end, and thereby to more than double the width of the opening. This necessitated two new main and one centre Warren girders of 28·8 metres (94 feet 6 inches) span for this opening, the replaced Warren girders being used elsewhere in place of the lattice girders. The work was carried out in 1895–96, the traffic being maintained. The Paper is illustrated by a plate of elevations, plans and sections, and details of the cost of the work are given:—

	£	s.	d.
The cost of the repairs of the piers and abutments was	2,459	15	6
Changing and partly renewing ironwork	3,155	14	10
Removal of river pier	483	10	8
	6,099	1	0

[1] It may be noted that the up and down traffic passes each to the right hand of the other instead of to the left, as general here.

D. G.

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High-level Bridge at Levensau on the Kaiser William Canal.

FÜLSCHER.

(Zeitschrift für Bauwesen, 1899, p. 99.)

Before entering on the description of the bridge proper this article gives an account of the works involved in the approaches.

The bridge is constructed to carry two lines of way and a footpath over the Kaiser William Canal. There are two main segmental arched ribs of 163·4 metres (536 feet) span, built parallel to one another at a distance of 12·6 metres. The rise of the arch is 21 metres (69 feet); the depth of the ribs at the centre is 3·2 metres (10·5 feet), and at the abutments it is greater, viz., 5·6 metres (18·4 feet). Each rib is hinged at the springings.

The platform of the bridge, consisting of longitudinal bearers and cross girders, is attached to the main ribs in such a fashion as to allow of its expansion and contraction independently as far as possible of the main structure. The attainment of this end has, in the Author's opinion, added considerably to the weight of the bridge. There is a wind-bracing girder constructed at the level of the permanent way platform, and another above this at a level to clear the loading gauge. Both of these girders are fixed laterally at two intermediate points by being attached to frameworks fixed to the main ribs. They are thus made into continuous girders of three spans.

From each of these two intermediate points a wind-bracing girder is constructed between the main ribs and carried down to the nearest abutment. That portion of the main structure between the two intermediate points above mentioned has no wind bracing between the arches, but the force of the wind is transferred from the arches on to the overhead wind-girder by means of stiff cross frames.

The main ribs were dimensioned according to the formula—

$$K = 800\left(1 \pm \tfrac{1}{2}\frac{S_{min}}{S_{max}}\right)$$

For the platform the stress allowed varied from 600 kilograms to 700 kilograms per square centimetre (3·8 tons to 4·4 tons per square inch). The bridge was constructed by means of staging.

W. B.

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Destruction of the Wide-Span Roof of the Electricity Gallery of the Paris Exhibition. A. DA CUNHA.

(La Nature, 17 December, 1898, p. 33.)

In consequence of insufficient strength in the shoring-up of the roof-trusses, two of the sections of the machinery gallery which had been successfully transported to their new position [1] were blown down by a violent gust of wind at 9.30 A.M. on the morning of the 9th December. The portion of the work destroyed comprised two bays, each 82 feet wide, having between them a space of 65·6 feet, which was in course of being filled in with new cross-girders. The third section, which would have rendered the gallery complete, was all in readiness for removal when the accident took place. A photograph shows the fallen roof-trusses and the wreck of the structure. The Author points out that it is difficult to impose upon the contractors the responsibility for this catastrophe, as the accident was chiefly caused by the delay in following on with the iron struts, which should have been fixed directly the ironwork was shifted to its new position. This delay was not caused in any way by the contractor responsible for removing the structure. The accident will not postpone the date of the final completion of the Exhibition buildings.

G. R. R.

The Moving Platform of Saint-Ouen.

(La Nature, 11 February, 1899, p. 164.)

In order to afford a practical demonstration of the working of the travelling platform, which will constitute one of the features of the Paris Exhibition of 1900, an experimental section has been erected at Saint-Ouen, a little way out of Paris. A description is given of this undertaking, illustrated with details, showing the mode of construction. The floors, three in number, rising one above the other, are supported on a staging elevated 7·54 feet above the ground. One of these floors, or platforms, is rigid; and the two others travel, the one at a speed of about 2½ miles an hour and the other at double this speed. It thus becomes possible to step from one platform on to the other—the movement of the lower one being only about the rate covered in walking slowly on level ground. The travelling platforms are really low trucks, alternately round-ended and concave-ended, so as to allow of sufficient play in passing round curves. The platforms will work on a curve of 33 feet in radius. The uppermost platform, which is driven the fastest, is the widest. Each platform-car carries a section of rail

[1] Minutes of Proceedings Inst. C.E., vol. cxxxv. p. 382.

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beneath it, which is driven electrically by means of a friction roller. These rollers are 82 feet apart. The weight of the trucks and passengers is sufficient to cause the rails to bite on the friction rollers and to avoid slipping. But each car has in addition small wheels on either side which run on rails laid for the purpose. The trial section is 546 yards in length, and has worked well, except that it is found to be very noisy. Measures will, however, be taken to prevent this noise in the continuous travelling platform at the Exhibition.

G. R. R.

Rainfall, Evaporation and Subsoil Percolation in the Haarlem Lake Reclamation. A. ELINK STERK.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1897–98, p. 63.)

In the Haarlem lake polder, observations of rainfall and evaporation, within the embankments of the reclamation, are recorded since 1861. The usual instruments are placed in four situations, one in the centre at Hoofddorp, and the others near the draining-engines on the circumference at Leeghwater, Cruquius, and Lynden. The collected records over the last 36 years show the average yearly rainfall for Hoofddorp at 784 millimetres, Leeghwater at 809 millimetres, Lynden at 764 millimetres, and Cruquius at 744 millimetres. Although these averages, taken over long periods, show but small differences, these are sometimes considerable if only short periods are considered. For instance, in 1866 the total rainfall for the year at Lynden was 130 millimetres less than at Hoofddorp, and in 1885 for October 80 millimetres more, evidently through local showers. To base calculations of great exactness on similar information would evidently be imprudent. The records of maximum and minimum rainfall are of more practical value. At the same time evaporation was observed by weight, in troughs filled with soil, standing free in the first years, but now placed in ponds and surrounded by water. In the former troughs the recorded evaporation often exceeded the recorded rainfall. The troughs surrounded with water indicate about 30 per cent. less evaporation and are considered more trustworthy. In this climate evaporation exceeding rainfall during considerable periods is an anomaly, and against observed facts. Some plants, however, very powerfully assist evaporation, even on days when the air is not sufficiently warm to evaporate water. The quantity of water to be pumped out is, however, much greater than that from rainfall less evaporation, and this excess is derived from subsoil percolation. The water-level in the inside draining-trenches, lying on an average 4 metres to 4·5 metres (13 feet to 15 feet) below the water-level of the surrounding or "ring" canals, this infiltration must be considerable. It is, however, difficult to arrive at an exact estimate of these quantities owing

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to the great variety in porousness of the subsoils on which the surrounding dams are laid. The Author also compares the records in Bohemia and at Nyon in Switzerland with those in the Netherlands, near Haarlem and Leyden, and concludes that evaporation of water from different soils is a very complicated phenomenon.

H. S.

Influence of Wind-Pressure on the Sea-Level at Helder.

JONKHEER F. L. ORTT.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1897–98, p. 75.)

In a Paper published in the "Tijdschrift" for 1896–97, page 117 (on the influence of wind and atmospheric pressure on the tides), this influence was investigated, as regards the Hook van Holland and Ymuiden, by comparing the observed with the calculated tidal rise and with the recorded wind-pressures and directions. The Author in this Paper endeavours to arrive at similar information by another method. He finds, however, that deviations from certain theoretical rules are recorded, the causes for which cannot with certainty be stated. The values of the coefficients for the Helder are as a rule 0·4 higher than those for the Hook or Ymuiden. A complication arises from the fact that the crest of the tide-wave at the Helder is mostly distinctly double, with a marked depression between such crests, one being due to the tide coming up through the English Channel, and the other from the tide-wave sweeping round Scotland. When the two high-waters coincide the rise is higher than with a double-headed crest. The results of the numerous calculations shown in the Paper indicate that the local barometric and other observations are not sufficient to account for the actually recorded facts, and it is thought most probable that the deviations from the mean amplitudes of the tidal waves, as calculated, are caused by conditions existing at the times in the Atlantic Ocean, of which for the present no records are obtainable. As a general rule it may be accepted that absolute absence of wind lowers the tide by 5·4 centimetres (2⅛ inches) on an average. The tides during west to north winds are of course higher than when the wind flows from the easterly direction, but whether the surface of the North Sea, during north-westerly winds, inclines towards the opposite English coast, cannot be decided until trustworthy synchronic records are obtainable from the western shore.

H. S.

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Stone Jetty from Madura to the Djamoeang Reef.

J. L. PIERSON.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1897–98, p. 91.)

The western entrance to the straits between the islands of Java and Madura, leading to the important harbour of Soerabaija, was subject to silting up by deposits from the Solo river on the Java coast. With the object of diminishing this evil influence, the eastern mouth of this river was closed and a new discharge channel provided towards the north and outside the straits. In addition to this work it was considered urgent to lay a leading dam from the western point of Madura towards deep water in a N.N.E. direction to intercept the tidal current coming up from the west, along the north shore of Java, and lead it with more force into the straits. It was presumed that the current so concentrated would deepen or at least maintain the navigable channel. The total length of this dam or jetty was to be 12·5 kilometres (about 8 miles) long, laid from the point at Oedjong-Pangka towards the coral-reef at Djamoeang in an average depth of 10 feet on a soft muddy bottom, the top a foot above high water at springs, 10 feet wide, with slopes of 2 to 1. The cone was to be of limestone rip-rap, the top and slopes to be covered with more regularly laid and heavier stone, properly packed, and 0·75 metre (2 feet 6 inches) thick. The estimate for the whole was 1,700,000 florins (£108,000). The order to proceed was given by the Government on the 22nd February, 1893, and the work started a few days later. Quarters for the supervising staff were built in proximity, as also the necessary godowns and magazines for explosives. At first great difficulty was experienced in obtaining labour, and later on severe epidemics of fever reduced the available force to a serious extent, sometimes 50 per cent. being laid up. The rip-rap was chiefly obtained from the inhabitants of the neighbouring coastlands, who brought it to the spot in their own boats or "praauws," and sunk it where directed. The quantities delivered were measured in the boats and paid for according to the carrying capacity of each to a certain load line, determined beforehand and registered. These native craft carried from 3 cubic metres to 20 cubic metres (6 tons to 40 tons). The price for this stone varied from 1·25 florin to 2 florins per cubic metre (4*s.* 2*d.* per ton to 6*s.* 8*d.* per ton). In addition to this supply quarries were opened for larger and more regularly shaped stone for the covering layers. Three sites were found where a calcareous rock cropped out to about 18 feet above the surface. The quarry faces were started at a height of 1 metre, the blast-holes being drilled by manual labour at distances of 2 feet 6 inches from the face, and 5 feet from each other, 3 feet 4 inches deep, paid for at the rate of 2*d.* each. The explosive used was Nobel's dynamite No. 1, with red fuse and sextuple detonators,

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supplied by the Borneo Company. The cartridges were 3 inches long, $\frac{7}{8}$ inch diameter, and five of them were used for a charge weighing 8 ounces. The limestone rock was of a hard and crystalline nature on the top, but at a depth below the surface of between 3 feet to 4 feet it was soft and brittle, so that there but little was broken out in pieces of suitable sizes, often even crumbling away to powder. This is why only about 6 tons of material were obtained for each kilogram of explosive used. The stone from these quarries, worked departmentally, was conveyed over narrow-gauge railway lines to the work. Gunpowder was but little used, and where tried gave unsatisfactory results owing to the dampness of the atmosphere in this climate. From these quarries 78·054 cubic metres (about 160,000 tons) were used in the work principally for the top layers, and 553,448 cubic metres (1,200,000 tons) from the native supply for the rip-rap cone. The stones from the quarries weighed 150 kilograms each on an average (330 lbs.), but in exposed situations blocks of 400 kilograms (880 lbs.) were placed. As had been expected, the mound settled down into the soft alluvial bottom to a depth of from 10 feet to 15 feet, and in one spot, where it crossed an ancient pass between the banks to a depth of 28 feet below the original surface. The total quantity of stone used was, however, but 178,500 cubic metres more than estimated for, the scouring action of currents sweeping round the advancing head of the mound being the principal agent in causing this excess in quantity. The work began in February, 1893, was completed in July, 1897, at a cost of 1,626,162 florins or 73,838 florins (£6,700) less than the estimate. Subsequent surveys and soundings in the pass show an improved state of the fair way which may reasonably be credited to these works. The Paper is illustrated with several plans and diagrams.

H. S.

New Harbour at Stettin. F. KRAUSE.

(Zeitschrift für Bauwesen, 1899, pp. 58–78.)

There are two docks of 100 metres (328 feet) in width each, and a combined length of over 700 metres (2,296 feet). The entrance is 100 metres wide, and without gates. A turning basin is provided between the entrance and the docks. The mean depth of water is 7 metres (23 feet). The total length of quays is 4,115 metres (4,526 yards). Alongside the quays are lines of railway with overhead travelling cranes. Behind these come single-storey sheds, then more lines of railway, with cranes and a cartway, and finally five-storey warehouses.

The warehouses are divided by cross-walls into sections, each about 30 metres (98 feet) long. Each of these sections is sub-divided by another cross-wall into two parts, which have

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access in common to a well on the side of the warehouse nearest the dock, containing a staircase and lift, and on the side furthest from the dock to a smaller well for access to railway waggons. The ground floors of the warehouses are of iron and concrete, the other floors of pine beams supported on oak columns. The whole of the quay walls, sheds, and buildings are on piled foundations.

The docks are fully equipped with buildings for machinery, including hydraulic and electric departments for the cranes and lighting respectively, engine-sheds and coaling stages, workshops and offices, dwelling houses, &c.

It is expected that electrically-driven cranes will be used at a future date, and provision is made for having an electrical-power installation to be entirely separate from the lighting system.

The article is illustrated in the text, and also by 3 plates.

W. B.

The New Harbour Works at Stettin.

(Archiv für Post und Telegraphie, 1898, p. 681.)

On 23rd September, 1898, the German Emperor declared the free harbour of Stettin open: the works had been five years in progress. The ship canal between the Danube and Oder has greatly added to the trade of the city. In 1876 the construction of the harbour and railway was begun at Dantzig. It was decided to make Stettin a free port, and work was begun in 1894; the total cost was to be £1,530,000. The free portion of the port of Stettin has an area of 150 acres, of which 55 acres are water surface. The harbour basin is 328 feet wide and has a depth of 23 feet. The east quay is 1,320 yards long, and the west quay 682 yards long. The spoil taken out by dredging has reached 1,343,070 cubic yards, and has been used wherever possible to raise the surface of the lands surrounding the harbour. When the whole of the proposed works are completed there will be a total length of 4,750 yards of quay front. Owing to the bad foundations deep piling was needed for the quays, the piles being 45 feet to 50 feet long and 14 inches to 16 inches in diameter. There are at present two sheds, each covering 6,500 square yards, and there is room for ten such sheds in all, and details are given of the sizes of the small cranes used in these sheds; behind the sheds are warehouses of six floors, and each warehouse is divided into twelve separate fireproof portions and lighted by electricity. The engine and boiler-house is on the south quay, where are also workshops and locomotive sheds. Hydraulic power is used and two 80 HP. pumps are installed, each capable of providing 1,480 cubic feet of water per hour at a pressure of 750 lbs. per square inch. For the complete harbour scheme 320 HP. will be required. For the quay service eighteen cranes and six capstans are in use, and for the warehouses two cranes, six lifts

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and six winches. The water for the hydraulic service can be heated by steam in winter. For the electric light one 130-HP. and one 300-HP. engine are installed and also a battery. Space is left so that plant for electric cranes may be installed hereafter.

E. R. D.

The New Harbour of Zee-Brugge at Heyst.

T. F. W. Conrad.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1898–99, p. 44.)

The new harbour near Heyst is intended as a port of call for the larger German and trans-Atlantic steamers. It consists of a pier, joined to the coastline on the west, and curving round towards the north and north-east, with a radius varying from 1,200 metres to 2,000 metres into a depth under ordinary low water of 9 metres, and ending at a distance of 1,000 metres from the shore. The convex side of the pier is turned towards the north-west, and under its shelter a space 300 metres wide is to be dredged to 8 metres depth below low water. To counteract the silting up by sand carried coastwise by the ebb current from the north, part of the pier, of a length of 306·87 metres, near the shore is to be of open tressel work on screw piles, so as to admit the flood current from the channel. The level of the pier at the top is to be at 2·50 metres above high water at springs; it is to be 54 metres wide, and to be protected on the outside by a wall 6 metres high. Sheds and cranes are to be placed on this pier, giving facility for trans-loading between vessels and the railway sidings laid on the quay. The harbour is to be also in communication with Bruges by a canal 8 metres in depth and of 22 metres bottom width. A plan and drawing illustrates the Paper.

H. S.

The Sea Commerce in German Ports for the Year 1896.

(Archiv für Post und Telegraphie, 1898, p. 617.)

The improvement in trade which took place in 1896 has since continued, and is noticeable in the increased commerce with German ports. From the tables published by the German Government it appears that while in the year 1875 the total for incoming and outgoing vessels was 87,558 ships, with 12,722,710 registered tonnage, the figures for 1896 were 147,536 ships, with 31,046,488 registered tonnage. The increase has therefore been 68·5 per cent. in number of ships, and 144 per cent. in tonnage; the latter figure is explained by the constant endeavour to build

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larger and larger vessels, as they earn better dividends than the small vessels. In the figures for 1875 there were 70,369 sailing vessels with 5,540,649 registered tonnage, and 17,189 steamships with 7,182,061 registered tonnage, while in 1896 the figures were 76,008 sailing ships with 4,776,574 registered tonnage, and 71,528 steam ships with 26,269,914 registered tonnage. While the number of sailing vessels has increased 8 per cent. their tonnage has decreased 13·8 per cent., the number of steam ships has increased 316·1 per cent. and the tonnage 265·8 per cent. Out of the total for 1896 there were 106,839 vessels of 16,225,936 registered tonnage belonging to Germany, and 40,697 vessels with 14,820,552 registered tonnage belonging to foreign nations. Tables are given showing the distribution by provinces of the German vessels, and also a table of foreign vessels, from which it appears that Great Britain heads the list with 8,813,312 registered tonnage. Details are also given respecting the coasting trade and the relative importance of the trade at the various ports of the kingdom.

E. R. D.

The New Graving Dock at Talcahuano (Chili). J. Kraus.

(Tijdschrift van het koninklijk Instituut van Ingenieurs, 1898–99, p. 1.)

Until recently no graving docks existed on the Pacific coast from Cape Horn to Canada, except two small wooden floating docks at Valparaiso and one at Callao. The Chilian Republic had thus to send her larger warships to Europe for repairs, causing much expense and inconvenience. In 1878 a French engineer was entrusted with the preparation of plans and estimates for a graving dock and repairing yard in the Bay of Talcahuano, situate in 36° 40′ south latitude—about the middle of the long Chilian coastline. This first project intended the work to be constructed within a concrete cofferdam jutting out into the sea from the shore and by means of pneumatic chambers, as had been successfully accomplished at Missiessy, near Toulon, in the south of France. In 1883 Mr. T. Dirks, a well-known Dutch engineer, was consulted, who submitted some improved designs. These being approved of by the Government of Chili, the contract for the construction was given to Messrs. Dussaud and Chambon for a sum of £546,320. The site chosen was on the Marinao reef at a distance of 600 metres from the shore, the work to be joined to the land by a dam. The dock was to give an available inside length of 188 metres, of which 122 metres with a bottom width of 23 metres, and a length in continuation of 66 metres with 17 metres width at bottom. The depth of the entrance cill during high-water neaps was to be 9·25 metres, and on the cill of the narrower part 8·36 metres. At a distance of 20 metres outward from the cill of the inner compartment an

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additional pontoon groove was to be provided, so as to give an additional length to this inner dock if required. The outside walls below low water were built up of concrete in layers through a compressed-air caisson suspended from lighters. The inside facing of the dock bottom, steps, and coping was of Seyenite and hard sandstone (arko quartzite). This was executed in the dry, as was also most of the inside excavation. The exhaust engines are four centrifugals, placed in couples. The concrete was of 2 parts broken stone to 1 part of mortar, consisting of 600 kilograms of hydraulic cement—Niel on Rupel—to the metre cube of sand (about 1 part cement to 3 parts sand). The Seyenite was obtained from a quarry at San Rosando, and the sandstone from that at Gomero, and conveyed to the works by rail. The Paper is illustrated with numerous plans, sections, and photographs.

H. S.

The Works on the Tiber.[1] M. Ronna.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, November, 1898, p. 1401.)

As if to remind the government of the responsibility which it had assumed in making Rome the capital of Italy, only three short months after the occupation, in December 1870 the worst floods occurred which had been recorded since 1637. On the 28th December at 10.0 P.M. the waters of the Tiber reached a height of 56·5 feet above datum and maintained this level for eight hours. Steps were at once taken by the appointment of a Commission in January, 1871, to investigate the causes of these inundations and to devise means to mitigate them, also to indicate the works needed to improve the course of the Tiber. This Commission, after inspecting the whole course of the river, appointed a sub-Commission of three of its members, Messrs. Betocchi, Canevari and Partini, to prepare a profile with sections and a plan for levelling the bed of the river from San Giuliano to Fiumicino. Two plans came before the Commission, the one drawn up by the President, Mr. Possenti, the other prepared by Mr. Canevari. These schemes were ultimately published with the Report of the Commission, and are considered by the Author with some other plans, which likewise were propounded at that time. The works of embankment and the improvement of the bed of the river, which were proposed and have subsequently been executed, are explained by reference to numerous illustrations and diagrams. The silting-up of the bed of the river is shown by sectional elevations of the various bridges, and calculations are appended of the area of the water-way required to deal with the flood-water. The scheme ulti-

[1] Minutes of Proceedings Inst. C.E., vol. cxxxi. p. 415.

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mately adopted negatived the proposed embankment of the upper reaches of the Tiber, and the excavation in certain places of a new channel. The various projects came before the Superior Council of Public Works, and their decisions issued in 1875 are dealt with in detail. Among other works which were then determined upon were the embankment of the Tiber in its passage through Rome to a height of 55·7 feet above datum, with a minimum width of water-way of 328 feet, the retention of the Tiberine island, the enlargement of the bridge of St. Angelo, the rebuilding of the Rotto and Cestio bridges, and the dredging of the river, together with the construction of outfall sewers. The Government did not at first adopt all these recommendations, and the works required have been executed in several sections. By means of photographs and elevations, the Author describes the progress of the improvements of the Tiber down to the end of December 1896. The total vote for these works was £4,200,000, of which nearly £3,000,000 have been expended. The Tiber has now been mastered, and future floods, comparable with those in the past, are no longer possible.

G. R. R.

The Training of the River Llobregat. P. G. Faria.

(Revista de Obras Públicas, 1898, p. 75 *et seq.*)

The Author points out that one of the most difficult works in hydraulic engineering is to alter the channel of rivers, especially when they are of a torrential character, like the Llobregat, a river which flows into the Mediterranean near Barcelona. Various alternative methods of dealing with the work are then discussed. Although very little water flows in the river-bed in summer, yet in the wet season a few days are sufficient to cause flooding of all the surrounding country and villages, and although doubtless the surface of the land is fertilised—as in the case of the Nile valley—yet the result could be far better attained by embanking the river, and providing suitable outlets for irrigation. Various engineers have at different periods been called upon by the Government to report upon the best method of dealing with the matter, and their reports are analysed.

Hydraulic measurements appear to prove that the maximum flow of water is from 124,000 cubic feet to 142,000 cubic feet per second. The present report advises that a new channel of trapezoidal section should be cut with a fall of 1·12 per thousand; the width would be 445 feet at the top and 400 feet at the bottom, with a depth of 23 feet at the sides and 26·2 feet in the centre; diagrams of the section are given, and also a plan showing the proposed canalization. Sections of embankments protected by rows of piles with fascine work filling, and also of stonework sustaining walls, are given. The Author lays stress upon the

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desirability of forming a road along the top of the embankment on each side of the river, and planting rows of trees along the sides so that the roots may firmly hold the whole mass together, and he cites various works in Spain where this plan has given great satisfaction. He then goes on to discuss the best means of draining the low-lying plains which have hitherto almost every year been inundated by the river, and have thus been a fruitful source of disease.

E. R. D.

The Baltic and Black Sea Canal.[1] GEORGES LEUGNY.

(La Revue Technique, 25 November, 1898, p. 512.)

The projected maritime canal from Riga on the Baltic to Kherson on the Black Sea will have a total length of 994 miles. Its width at water-level is fixed at 213 feet, and at bottom 115 feet, with a uniform depth of 28 feet. The canal begins at the estuary of the Duna, and it follows the principal arm of that river up to its confluence with the Meritza, which takes place a little below the town of Dünaburg. Here for the first time the canal involves excavations in traversing the valley of the Meritza, and having absorbed the waters of numerous small streams and appropriated the beds of others, it reaches a chain of lakes and rejoins the Bérésina at Lake Pelik. The canal from this point follows the level of the valley or winds through the above river, cutting off numerous bends, till its junction with the Dnieper. Here a lake will be formed situated in a marshy country. The canal at this point enters the bed of the Dnieper and follows the course of this river to its mouth. A second lake will be formed at the junction of the Dnieper with the Pripet. A sketch map is given to show the course of the canal. The chief feature is that, notwithstanding the fact that it attains a total elevation of 396 feet above datum (the level at either extremity) in its central zone, or summit-level, the canal will be constructed throughout without locks, and will obtain its water-supply from the rivers through which it passes. These will be trained, dammed back, and furnished with locks, and the superabundant water will be available for irrigation. A sketch section is given to show the falls in each portion of the canal. The chief technical difficulty is encountered in the cataracts on the Dnieper, which are nine in number and extend over a length of 41·6 miles. An account is given of the mode in which these obstructions will be overcome, and details and illustrations are appended showing the method of forming the embankments, training-dams, river banks, &c., in the various portions of the canal. The estimated outlay for the first part of the work is £20,000,000 sterling. Among the objections

[1] Minutes of Proceedings Inst. C.E., vol. cxxix. p. 418.

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which have been urged against the scheme are these: that such a canal cannot be constructed without locks; that it will be frozen over during a portion of the year; that the cost will greatly exceed the estimates; and that the expenses of maintenance will be extremely heavy.

G. R. R.

The Present Status of the Panama Canal.

General H. L. Abbott, Corps of Engineers, U.S.A.

(Engineering News, New York, 6 October, 1898, p. 210.)

The Author, a member of a commission of engineers, has carefully examined the route and the labours of investigation of the new company organised in October, 1894, which are concluded. The 43 miles of inland construction are divided into four sections: (1) 14·88 miles between Colon on the Atlantic side and Bohio, now essentially excavated; (2) 13·64 miles between Bohio and Obispo, through a lake created by a dam at Bohio in the valley of the river Chagres, at a level of 55·76 feet, and accessible by two double locks at Bohio; (3) 10 miles from Obispo, where the canal leaves the Chagres and enters the valley of its tributary, the Obispo, to the watershed, the Culebra mountain, and through the valley of the Rio Grande to Miraflores; (4) 4·34 miles between Miraflores and La Boca, near Panama on the Pacific side, now essentially excavated. The problem, therefore, lies in the two inner sections and comprises the arrangement of the locks and their levels, the regulation of the waters of the Chagres in the rainy season for the supply of the summit of the canal during the dry season, and the supply of horse-power for operating the locks and for lighting. Trial excavations, borings, gauging of the water-courses, and estimates have been made in the most elaborate manner by the new company, resulting in a plan for placing the bottom of the canal at the summit, 68 feet, and the maximum water level 102·5 feet above the sea level. This is reached on the Atlantic side by two double locks at Bohio, effecting a rise from zero to 65·6 feet, and by two double locks at Obispo for the remaining 36·9 feet. On the other side of the summit will be one double lock at Paraiso, lowering the level to 76·25 feet; two double locks at Pedro-Miguel, lowering it to 20·5 feet; and a tidal lock at Miraflores, lowering it to sea level of the Pacific, which varies between +10 feet and −10 feet.

The depth of water in the canal will be 9 metres (29·52 feet), and the width at bottom generally 30 metres (98·4 feet). Curves have a radius of 9,840 feet, except at Bohio, where radii of 8,200 feet and 6,560 feet, with an enlargement of bottom to 203 feet, occur, and at Obispo where the radius is 5,576 feet, and the bottom width 262·4 feet. At intervals of about 5 miles there

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will be enlargements 2,000 feet long and 200 feet wide for the passing of ships. The larger of the double locks will be 738 feet long, 82 feet wide, and 32·8 feet deep in the middle, while the dimensions of the smaller lock will be 426·4 feet by 59·04 feet by 32·8 feet. The two great difficulties, the damming of the Chagres and the cutting through the Culebra, at one time considered so serious, now admit of satisfactory solution. There will be a dam at Bohio with a crest length of 1,286 feet and a depth of 75·4 feet, and a concrete wall at Alhaguela with a crest length of 936·4 feet and a depth of 134·5 feet. The mass of earth to be excavated in the Culebra will be about 15 million cubic yards. Numerous borings, the sinking of pits, and the making of a tunnel 689 feet long at a level of 134 feet, have ascertained the soil to be indurated clay schist, requiring blasting, and then rock, the upper soft strata being already excavated. Compared with the Panama Canal the Nicaragua Canal will be about four times as long, the number of locks the same, and the rise about 7 feet more.

M. A. E.

The Nicaragua Canal. H. Claus.

(Annalen für Gewerbe und Bauwesen, 15 December, 1898, p. 236.)

The political events of the past few years have called renewed attention to the importance to the United States of establishing a means of communication for navigable vessels across the isthmus between the Atlantic and Pacific oceans. An account is given of the various proposals which have from time to time been put forward to effect this object, the three principal schemes being the Panama Canal, the Tehuantepek Ship-Railway, and the Nicaragua Canal. The relative positions of each of these undertakings are explained by reference to a sketch map. No doubt the Panama Canal, begun by a company promoted in 1882 by Ferdinand de Lesseps, would, if it could be completed, prove to be the best of these projects, but it is so far away from the United States that it would scarcely prove a desirable solution of the question from the American point of view. The ship-railway, for which a plan was prepared by Captain James Eads so far back as 1880, has much in its favour in point of proximity to the States. An explanation is given of the chief features of this scheme, for which a 99 years' concession was obtained by Captain Eads from the Mexican Government in 1881. The canal through the Lake of Nicaragua, which affords the only other possible solution of the problem, has much to recommend it. The length from end to end would be 169·6 miles, but only 28·5 miles would have to be excavated, as the Lake of Nicaragua and the waterways of several rivers could be utilized for the remainder. Figures are given to show the saving in mileage which the construction of the canal would

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effect, and the opinions of Prof. Haupt and Mr. Joseph Nimmo are quoted respecting its value and importance. It is pointed out that the vast growth in railway communication across the mainland of America, where no less than thirteen trunk-lines are either projected or are now in existence, must prove a powerful drawback to the ultimate success of a canal, and it is even asserted that the railway interest would have nothing to fear from the competition of such a canal if executed, as it could not hope to command more than a very small percentage of the trans-continental traffic.

G. R. R.

Canal Lifts. Fr. Jebens.

(Zeitschrift für Binnen-Schiffahrt, vol. v., pp. 331–333.)

According to the Author, the principal objection to lifts moving up and down an inclined plane is the tendency of the water in the troughs to accumulate by the force of inertia at the one side in case the speed is increased or diminished beyond a given ratio, as well as in the event of irregular speed and of sudden stoppages. In the first-named circumstances the extent of the displacement varies directly with the length of surface of the trough, measured in the direction of the movement on the inclined plane, so that by mounting the troughs transversely the inconvenience is diminished. In the case, however, of sudden stoppages, the actual force of inertia exerted by the water at the moment of arrest is independent of the manner in which the troughs are mounted.

He considers that the greatest security is afforded by vertical lifts working with threaded guide-rods, as in use at Heinrichenburg (Dortmund-Ems Canal), since in this system (provided the pitch of the threads be slow) it is impossible for the lift-troughs to alter their position unless the guide-rods are set in motion. A saving in motive-power may, however, be effected by making the guide-rods stationary and imparting motion to the nuts through which the rods are passed.

C. S.

The Crystal Springs Dam, California. Enos Brown.

(The Scientific American, 17 December, 1898, p. 392.)

This, the highest dam in the United States, is located 5 miles west of San Mateo, Cal., and 20 miles from San Francisco. At the site of the dam the rocky walls of the cañon meet within 700 feet at the crest of a dam of the present height, 145 feet, which forms a lake 9 miles long. The dam is 40 feet thick at the crest and 176 feet at the base, the front slope being 1 horizontally to 4 vertically, and the slope at the back 1 to 1, starting from the

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toe and ending in the upper 60 feet with a slope of 1 horizontally to 2 vertically, the two slopes being connected by a curve. The convex face of the dam upstream is curved to a radius of 637 feet. It is contemplated raising the dam 30 feet, when the reservoir will hold 24,000 million gallons (imperial). To avoid the difficulty from shrinkage and cracking of the concrete of which the dam is constructed, it was decided to build it of separate blocks of concrete averaging 40 feet long, 30 feet broad, and 8 feet deep, having notches and projections on their tops and sides, each block being completed the same day. The blocks were built far enough apart to allow of a second set being laid between them after the first had hardened, breaking joint and interlocking with them. It was also arranged that the joints should be broken vertically.

A. W. B.

Water-Storage in Mexico.

(Organ des Verein der Bohrtechniker, 1 September, 1898, p. 8.)

The greater part of the Mexican Republic consists of a mountainous table-land with few rivers, and, as the rainy season only lasts from 3 months to 6 months, it is necessary to catch and store a portion of the rainfall in order to supply the water required for irrigation during the drier months of the year. Under the influence of irrigation the table-land, which in its natural state is a desert, becomes extremely fertile. The State of San Luis de Potosi is especially dependent upon irrigation both for agricultural purposes and also for the water supply of the capital. From 3¾ miles to 5 miles to the west of the town of San Luis Potosi lies the valley of Escalerillas, across which a dam, about 98 feet high, has been in course of construction for the last 3 years. The rock is a quartz porphyry, full of fissures, and its unreliable character has added considerably to the difficulties of construction of the dam. The artificial lake of Escalerillas will contain 9,810,000 cubic yards to 10,464,170 cubic yards (7,500,000 cubic metres to 8,000,000 cubic metres), and will cover an area 3 miles long and 186 miles wide at the widest part of the valley. For seasons of exceptionally heavy rainfall overflows 33 yards wide are provided on each side of the retaining-wall, and a safety dam 11½ feet high is also provided on the top of the main retaining-wall. Including the foundations, which are 48 feet deep, the total height of the dam is 159 feet. The work was designed by Mr. W. Reiter and is being carried out by means of Indian and convict labour.

W. F. R.

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The System of Impounding Thermal Springs by the Ancients.

L. DE LAUNAY.

(La Nature, 31 December, 1898, p. 66.)

The Author, who has been engaged in the study of the various methods of developing, utilizing, and dealing with thermo-mineral springs at the present time, has had occasion to investigate the works executed, even as far back as the Roman period, for impounding and rendering available, sometimes at considerable distances from their source, the famous thermal springs known to the ancients. It is pointed out that some of these works belong to a period anterior even to the Roman sway. Such, for instance, are the aqueduct of Siloam dating back to the time of Hezekiah, with one of the most ancient Hebrew inscriptions recorded, and certain Phœnician or early Greek works, amongst which mention is made of a tunnel 1,312 yards in length beneath the ruins of the Acropolis at Samos, the subterranean aqueduct at Mycenæ, discovered by Dr. Schliemann, and the works of the Phœnicians at Tyre, described by Strabo. An account is given of the different categories of works undertaken in connection with various named springs, some being in the nature of galleries or adits, some being superficial excavations or cuttings, and some taking the form of concrete reservoirs or dams to keep out other supplies, either of cold water or of water of a different quality. In explanation of these various methods of carrying out the above undertakings, photographs are given of the Roman works in connection with the thermal springs at Eledja at Taurus-in-Cilicia, while the arrangement of the reservoir and pumps at Bourbon-l'Archamboult (Allier), and of the galleries, adits and mines at Pozzuola, near Naples, are shown in plan and section. Certain of the modern methods of boring for springs were apparently quite unknown to the ancients, and they were unacquainted with the ingenious system termed by its inventor, Mr. Francois, who died in 1890, the "method of reciprocal hydrostatic pressures," which depends upon the fact that cold water may be in actual contact with hot water without mixing with the same. This method has been put in practice in order to direct thermal springs to some point of issue agreed upon, by opposing a column of cold water to all other hot-water exits, with the exception of the desired outlet.

G. R. R.

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Continuous and Uniform Flow of Liquids. VICTOR FOURNIÉ.

(Annales des Ponts et Chaussées, part iii., 1898, p. 1.)

The Author enunciates two empirical formulas devised by him for measuring the uniform flow of liquids, the first relating to circular pipes, and the second to open channels. In these formulas terms are introduced involving the temperature of the water, which he considers of much importance, and also constants of adherence and roughness of the walls of the pipe. He compares the results obtained from the use of these formulas with the experiments of Poiseuille and the formulas of Prony, Darcy, and Bazin; and, in conclusion, recommends further study in the conditions governing the flow of water in open channels, the laws of which are not known with the exactness which pertains to other branches of hydraulics.

H. I. J.

Progress on the New Waterworks for Cincinnati, Ohio.

(Engineering News, New York, 8 December, 1898, p. 354.)

The new water supply of the city of Cincinnati comprises a river intake pier and tunnel, a primary pumping station, settling reservoirs, filter plant, clear-water basin at California, long gravity main, second pumping station and a force main to the present distributing reservoir, at an estimated cost of $6,500,000 in bonds. The turbidity of the Ohio water ranges from 5 to 2,500 weight parts per million parts of suspended matter, being clay when at the minimum, and sand, silt and coarse clay at the maximum; organic matter comes from sewage and surface, and bacteria range from 100 to 100,000 per cubic centimetre. An experimental station for determining questions of sedimentation, and for deciding between slow sand and mechanical filtration, was erected at a cost of $23,000, and is in operation since March, 1898. It consists of four settling tanks, 25 feet diameter and 34 feet depth, in which the Ohio water is allowed 3 days to settle; it then passes by gravity into an equalising tank and thence to fifteen wooden filter tanks, about 12 feet diameter, and different depths for thicknesses of sand from 5 feet to 1 foot, with 4 feet depth of water each. These trial filter beds have been continually worked at the rate of from 1·5 to 4 million gallons per acre per day. The results to be laid down in the Cincinnati report are awaited with great interest. Meanwhile it appears that the bacteria are easier to remove than the turbidity, owing to their being larger than the particles of clay.

The channel of the Ohio river being near the opposite bank, where the Covington pump-house stands, a tunnel 1,400 feet long and 7 feet diameter is required under the bottom of the river, with

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a protected stand-pipe at the opposite end projecting above high-water, which is 70 feet above low-water. The stand-pipe or suction-shaft on the Cincinnati side, at California, is in the centre of a masonry pump-pit of 98 feet inner diameter, the bottom of which is 10 feet below low-water, sunk on a timber caisson of 129 feet diameter at the cutting edge and of 20 feet depth. The masonry, increasing in thickness from 4 feet 3 inches to 14 feet 6 inches at the bottom, encloses a $\frac{1}{4}$-inch riveted steel shell 140 feet diameter.

The construction is shown by photograph and drawings. From this pit the water will be pumped to two subsiding reservoirs of a combined capacity of 345 million gallons, filled and drawn from alternately. Thus a daily output of 57 million gallons would leave 3 days, and one of 86 millions 2 days for subsidence. A third reservoir of 120 million gallons capacity is contemplated for future requirements. From these reservoirs, 138 feet to 107 feet above low-water, the water will flow to the filter-beds and the clear-water basin at a level of 93 feet to 73 feet, and through the long main to the well, 30 feet above low-water, of the second pumping station. Here it will be pumped to the existing distributing reservoir at a level of 240 feet. The works are designed for a daily consumption of 60 million gallons, with provision for an increase of 50 per cent.

M. A. E.

The Accuracy and Durability of Water-Meters.

J. W. Hill, M. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, January, 1899, p. 1.)

The Author investigates the accuracy of a number of makes of three different varieties of $\frac{5}{8}$-inch water-meters, viz., piston-meters, disk-meters, and inferential meters with $\frac{1}{2}$-inch connections. The meters were attached to a $\frac{3}{4}$-inch service-pipe from a 10-inch diameter main, the static pressure in which varied from 85 lbs. to 106 lbs. on the square inch. A pressure-gauge was connected to measure the higher pressures and a mercury manometer for the lower pressures on both the inlet and outlet sides. The varying rates of discharge were obtained by placing, in the short length of $\frac{3}{4}$-inch pipe attached to the outlet, disks with a central perforation ranging from $\frac{1}{2}$ inch to $\frac{1}{32}$ inch diameter, the stop-cock on the supply side being always full open during a test. These disks caused the discharge to vary from about 900 gallons per hour to about 10 gallons per hour. The water passing through the meters was discharged into a cask on a platform scale which read to $\frac{1}{4}$ lb.

The Author found the error for these varying discharges insignificant, except in some cases with the low discharges.

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A further series of tests showed the loss of pressure in the different classes of meters. With the greater discharges these were about 20 lbs. for the piston-meters, 15 lbs. for the disk-meters, and over 30 lbs. for the inferential meter tested, ranging to less than 1 lb. with the smaller discharges. The Author found the disk-meters to act as efficient detectors for small leaks, which the meter could not measure, by the vibration of its disk on its ball-bearings.

A. W. B.

The Bergé Process of Purifying Drinking-Water.

H. E. P. Cottrell, Assoc. M. Inst. C.E.

(Engineering, 16 December 1898, p. 767.)

This process is used for sterilization of drinking-water by the application of "Polozone," either in the form of a gas or solution. Polozone (ClO_2) is formed by the chemical action of sulphuric acid upon chlorate of potash. It is a more energetic oxidizer than ozone, readily burning up organic matter. Though fatal to microbe life, it is harmless to men or animals. The worst river water requires only 2 grammes of polozone per cubic metre, costing 3*s.* 8*d.* per million gallons, to render it fit for drinking. For treating Thames water at the intake, 1 gramme per cubic metre would be sufficient, while to effect absolute sterilization of the water after passing the sand filters would cost only 5*d.* per million gallons. The application of "polozone" in the form of a solution permits the sterilization of water, either in large reservoirs or in distributing mains, or in the bottle or glass on the table. In July, 1898, the Bergé process was exhaustively tested with a view to its adoption at Ostend. The commission conducting the experiments reported that the process was perfectly efficacious, and that the action of polozone was remarkably energetic and rapid. The experiments showed that filtration through polerite may be dispensed with.

A. P. H.

Acetylene Lighting.

(Archiv für Post und Telegraphie, 1898, p. 720.)

After a general comparison of the colours of various sources of light, it is pointed out that the acetylene flame gives probably the nearest approach to sunlight, and is specially valuable for picture lighting. It is then shown that while some sources of light are useful for outdoor work they are of no use for living rooms. Reference is made to the recent work of Dr. O. Frölich and H. Herzfeld, and a table of candle-powers and costs is given in which

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fifteen different sources of light are compared. The prices of the materials are given, and the following figures show the relative costs of some of the various methods of illumination :—

Incandescent oil-lamp	0·76
„ gas light	0·96
„ spirit-lamp	1·20
Acetylene lamp	2·99
Compressed oil-gas lamp	5·46
Coal-gas, batswing burner	5·52
Electric glow-lamp	5·63
„ arc-lamp	2·18
Water-gas	0·72

In the above list the costs of incandescent mantles and renewals are not included. It is also stated that whereas the naked mantles are too dazzling for the eyes, the acetylene flame is unobjectionable in this respect. Acetylene lighting plants are said to occupy a place between oil illumination and coal-gas or electric plants, and are suited for installations of 6 to 1,000 burners. Reference is made to the increasing use of acetylene for railway lighting, and on the Berlin State Railway it is largely employed.

E. R. D.

Advantages and Disadvantages of Existing Systems of Electrical Traction. E. A. Ziffer.

(Zeitschrift für Transport-wesen und Strassenbau, vol. xv. [29], pp. 462–466; [30], pp. 478–480; [31], pp. 495–497; [32], pp. 510–512.)

From the materials at his disposal, and which are detailed in the Paper, the Author comes to the following conclusions :—

(1) Accumulators render the system independent of the breakdown of individual cars, and preclude the possibility of telegraph and telephone circuits being affected by the current, besides freeing the streets from unsightly cable standards. On the other hand, the great weight of the accumulators, the rapid wear of the plates, low efficiency in ascending steep gradients, and the high working expenses, are disadvantageous.

(2) The overhead system has been thoroughly tested, is cheap in installation and economical in working. It could also be replaced in a simple manner by any improved system, the expense of conversion from horse-traction being, moreover, low. The æsthetic objections raised against the overhead wires are somewhat exaggerated, and the risk of affecting other electrical circuits is capable of being minimized by suitable precautions.

(3) Underground wire system. Here again there are no unsightly standards and no risk of influencing other circuits, against which must be set off the inaccessibility and difficulty of cleaning and draining the channel in which the cable is laid.

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(4) Of the mixed systems, that with overhead wires and accumulators for dispensing with standards in the better parts of a town is advantageous only when the latter method of driving is predominant. The second division, overhead and underground wires, is cheaper to work than the other, and is only preferable when the underground wires are in short sections, the system as a whole being attended with the defects of the underground system, besides being expensive to convert into any other.

(5) Underground wire with closed cable channel. This system possesses æsthetic advantages, but the insulation is expensive, the interchange of contact fittings difficult, and the channel is hard to keep clean.

(6) The triple-rail system is the cheapest to instal of any, but requires a special road-bed, and is thus only suitable for overhead or underground tracks, the great waste of current also rendering it expensive to work.

(7) The polyphase (rotary current) system is more efficient than the corresponding alternating-current system, but can only be resorted to where there are large central stations supplying this class of current for lighting and power.

(8) The uniphase alternating-current system merits attention, the motors exhibiting all the advantages of induction motors. The system has, however, still to be tried.

C. S.

Electric Traction on the Orleans Railway Extension in Paris.

(Revue générale des Chemins de fer, 1898, p. 384.)

Owing to the long length of tunnel in the extension which the Orleans Company are making in Paris, and the underground arrangement of the new terminus at the Quai D'Orsay, the question of smokeless locomotives has received the most careful attention. With the exception of a few "trains de luxe," which do not stop at Austerlitz, and whose smoke would not much affect the air, a change of engines can be made in the 2-minutes stop at that station; and the company, acting on the advice of their engineers, sent specially to the United States to report on Electric Traction, are preparing to work this section of the line, a distance of about 2·3 miles, with electric locomotives.

Owing to the local conditions governing the choice of a site, the central power station has been located at Ivry, a distance of about 3·3 miles from the terminus. This has necessitated the employment of high-tension current, the form chosen being triphase at 5,500 volts and 25 cycles, which is generated by two 1,000-kilowatt machines. On the traction circuit two sub-stations reduce the current by fixed transformers to 550 volts, and supply two 250-kilowatt converters, which, running at 500 revolutions per minute, supply continuous current at 550 volts. A battery of accumu-

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lators, fixed in each sub-station, is connected in such a manner as to provide the extra current absorbed by the trains during the short period of running. A separate circuit provides for the lighting of the stations and approaches.

The primary distribution is by underground armoured three-wire cables, and the secondary by a third rail laid between the running rails and isolated by blocks of paraffined wood. The return current flows along the running rails. The locomotives are provided with slippers to collect the current, and also with arms for certain portions of the line where overhead wires are used.

The traffic, which is estimated at 150 trains per day, will be worked by eight locomotives. These are eight-wheelers, provided with four series motors, each driving one axle by a simple gear. Each locomotive has a normal power of 500 kilowatts, and weighs 40 tons to 46 tons, and will draw a train of 250 tons from the Quai D'Orsay to Austerlitz without an intermediate stop in 7 minutes; or start a train of 350 tons on a maximum grade of 1 in 92. A train of 200 tons will absorb about 650 kilowatts at starting, and 250 kilowatts when running at full speed.

The cost of the works, the primary circuit, the sub-stations, the secondary circuit, and the eight locomotives, is approximately £122,320.

H. I. J.

The Lausanne Electric Tramways.

C. Du Riche Preller, Assoc. M. Inst. C.E.

(Engineering, 16 December, 1898, p. 769.)

This system of tramways is remarkable, owing to the situation of Lausanne on the steep slopes rising from Lake Geneva, for severe gradients and sharp curves. Of the total length of 16 miles, 3 per cent. is level, the gradient of the remaining 97 per cent. varying from 3 per cent. to 11 per cent., the latter being the steepest gradient worked by simple adhesion. The average of the whole system is 3·5 per cent. The sharpest curve has a radius of 46 feet. The metre gauge is employed, the total weight of the permanent way being 170 lbs. per yard. The system is divided into five sections or branches, each having its own underground feeder cables. The return circuit is through the rails, which are electrically bonded at each joint, and, in addition, through three insulated return conductors. The generating plant comprises three 150-HP. Crossley gas-engines, each driving a direct-coupled Thury six-pole continuous-current dynamo. The gas is generated in Fichet and Heurtey's generators, being a modification of the Dowson plant. The fuel used amounts to 1·3 lb. of poor and small sized coal per HP.-hour. Each car is fitted with two 20-HP. four-pole Thury motors. The cars are provided with mechanical

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as well as electrical brakes, the latter consisting of the two motors, which are run as generators acting on the resistances, thus limiting the speed to 5 miles an hour. The cars are heated by electrical radiators. The total working expenses are 6*d.* per car-mile. The fares are differential, according to the equivalent length of the gradients.

A. P. H.

Falk Joints for Tramway Lines. ARSÈNE MAGNIER.

(La Revue Technique, 10 January, 1899, p. 3.)

It is pointed out that among the chief causes of rapid wear in the case of rails laid flush with the road surface are the concussions at the joints, due to the defective bolting together of the fish-plates, which cannot be reached without taking up the paving setts. Many plans have been proposed for overcoming this difficulty, among which the Author refers to the process of electrically welding lugs on to the ends of the rails, adopted at Boston in 1893, but abandoned, probably on the score of expense, and to the system of making joints of cast iron, introduced by Falk in 1894. This latter plan has been carried out at numerous places in America and in France—at Lyons, Paris, Marseilles, Havre and Rouen. An account is given, with illustrations, of the mode of running the joints and of the plant employed for this purpose. It is of paramount importance that the ends of the rails to be united should be thoroughly cleansed, and the plan of effecting this is explained. Photographs show the method of clamping together the rails, fixing the moulds in position, and running in the cast iron to form the joint. The construction of the portable cupola-furnace is described, and an account is given of the staff needed to work the plant. From sixty to seventy joints can be made in one run, which usually takes place at night. The form of the joint made use of differs somewhat in the case of the various companies, and the joint ranges from 81 lbs. to 136 lbs. in weight. The metal being run into the mould at a temperature of 1,400° C., it is stated by the inventor to soften the rail ends somewhat and to effect a partial penetration; but the Author states that in the case of numerous joints from time to time examined at Marseilles, no welding effect has been observed, on the contrary, a clear line of demarcation always exists between the cast and the wrought iron. The results of some experiments are given regarding the conductivity of such joints if the rails are used electrically. It is stated that though joints made on this system are costly, they undoubtedly prolong the life of the rail and render the traction more smooth. They save expense in maintenance and increase the electrical conductivity of the road.

G. R. R.

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Quick Charging Accumulators for Electric Traction on Tramways. F. Drouin.

(Mémoires de la Société des Ingénieurs Civils de France, 1898, part x. p. 30.)

This Paper describes the tramway system on the three lines of the Madeleine. The installation made in 1896 by the Société Industrielle des Moteurs differs from other systems in that the accumulators are charged very rapidly at the end of each journey during the stoppage of the vehicle. This system was devised as the trolley system could not be adopted, and the employment of movable accumulators would have necessitated three charging and changing stations.

The vehicles used weigh when charged 14 tons, of which the accumulators weigh 3·6 tons. The battery is composed of 200 cells arranged under the seats, and a switch connects them with either the charging or discharging circuit, the former consisting of two flexible cables, which are connected to the power-station by underground feeders. The power-station is situated at the Quai National, and contains three 120-kilowatt generators, which supply current at a tension of 600 volts.

The rapid charging of the accumulators renders necessary a special arrangement of the cells, viz., (1) the use of electrodes with a very large surface, (2) the charging at a constant voltage, and the use of a part only of the maximum capacity of the battery.

The Author gives particulars of the principal details of the tramway, and describes experiments made to determine the resistance of the vehicles.

H. I. J.

A New General Formula for Train Resistance.

(Street Railway Journal, February, 1899.)

The ordinary method of obtaining data for the calculation of train resistances is to work from indicator cards taken on the engine when drawing trains at a constant speed on the level, an arbitrary allowance being made for engine friction. This method, the Author points out, is unreliable, owing to the impossibility of finding suitable lengths of level line and of maintaining constant speeds. He brings forward a formula, worked out by Mr. John Lundie, as a result of long tests of trains in actual service, in which the determination of train resistance is based on speed curves obtained from trains "coasting" from any speed to a dead stop. This method gives the gross resistance due to all causes, and also (the frictional resistance being reasonably constant within wide ranges of speed) enables the resistance due to the air

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to be determined, being the difference between the actual curve and a straight line joining the full speed and full stop.

The formula is as follows:—

$$R = 4 + S\left(0{\cdot}2 + \frac{14}{35 + T}\right),$$

where T = weight of the transportation unit in tons (2,000 lbs.).
R = resistance in lbs. per ton.
S = speed in miles per hour.

The expression forming the multiple of S has been mathematically developed from the results obtained by Mr. Lundie, and is proportional to the tangents of the angles made by the lines developed for certain weights, as shown on the speed diagrams.

The formula has been tested against the results obtained by the Stroudley, Sinclair, and Dudley tests of train resistances, and also experiments made on the Philadelphia and Reading Railway, and on the Central Railway of New Jersey. The formula checks these results very closely, though in every case but one the results obtained are slightly higher than the observed results. The tests checked give a range of weights from 200 to 400 tons, and of speeds from 40 to 70 miles per hour, being weights and speeds upon which Mr. Lundie himself has made no experiments; the data on which his formula is founded, and for which it is accurate, being for weights of 20 to 100 tons and speeds of 5 to 30 miles per hour.

The Author points out that when a general formula, deduced from a large number of experiments within a comparatively narrow range of action, is found equally applicable over a much wider range, a strong presumption in favour of its soundness is established. So far, however, as freight trains are concerned, the formula results do not agree with those obtained in actual practice, the difference in the case of a 940-ton train, at 20 miles per hour, being 3 lbs. per ton. He considers that it would be of interest to gather together reliable results of freight-train tests and plot them diagrammatically, in order to find what modification of this formula would be necessary to make it applicable to this work, and thinks that in all probability a formula could be evolved possessing the characteristics of that developed by Mr. Lundie, and applicable to all classes of trains.

In conclusion, the Author desires that the widest comment and criticism may be given to this formula in order to test its reliability, considering that a means of accurately determining train resistances would be a very valuable aid to the railway engineer.

The Paper is illustrated by two diagrams, and a Table showing the application of the Lundie formula to train-resistance tests.

H. I. J.

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Railways as a Means of Penetrating New Countries.

ANNENKOFF.

(Bulletin of the International Railway Congress, 1898, p. 1348.)

The Author describes the means adopted and the plant used in the construction of a railway across the uninhabited desert which lies between the Caspian and Aral Seas.

The sole means of transport being natives or dromedaries, it was decided to work the railway from a base on the Caspian Sea, Mikhailovsk Bay being chosen as the port. Here were established reservoirs holding 77,000 gallons, in which was stored water distilled from the Caspian Sea, and which served as a supply for the stations and locomotives; also stores and materials of construction.

The railway was constructed from one end only, all materials being carried out on the completed portion. The labour was provided by two special railway corps formed of drafts from various regiments which had previously been engaged in railway work, and also of recruits of all classes who had received technical training. The native Turcomans were also found to possess excellent qualities for navvy work, and more offered themselves than could be employed. Two trains were provided, one a transport train composed of living-cars, dining-rooms, kitchens, &c., and the other a materials train. The method adopted was to put in a siding every 5 miles or 6 miles, into which the transport train was run; the materials train was then brought up to the end of the completed line, the rails, sleepers, &c., unloaded, and the work of construction pushed ahead. Seven groups of men, each under the charge of a non-commissioned officer, carried out the operations of rail-laying, the first group marking out the position for the sleepers and rails, and the last group with shovels adjusted the permanent way and corrected the levels. By this arrangement from 2 miles to 5 miles were laid per day.

In order to run as many trains as possible over a single line the stations are arranged about 15 miles apart, which allows for twelve trains each way during 24 hours. The steepest gradient is 1 in 166, and the sharpest curve has a radius of 26 chains.

No special difficulties were met with in the construction, the greatest being the providing of a protection against the drifting of the sand. This was successfully overcome by making an embankment on each side of the line in the most exposed parts, and forming fascines of the native brushwood on the top, which in the greater number of cases took root and formed a most efficient protection.

The Author gives a detailed description of the method of construction, the food provided for the men, medical attendance, and sanitary regulations; and in conclusion points to the success of

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this railway, which was primarily intended for military purposes, but has now developed the industries of the country to a very great extent, as an example of what can be done in other as yet undeveloped countries.

H. I. J.

Speed-Gauging for Railway Trains.

MAX VON LEBER, Member of Council for Austrian State Railways.

(Organ für die Fortschritte des Eisenbahnwesens, 1898, p. 242.)

In special cases, where it is required to ascertain with absolute certainty the speed of trains, an electrical apparatus is employed. This is applicable at certain fixed points only. Another system, of far more extended application, is to fix the registering apparatus on the vehicle in motion. Many appliances of this description are available. The Author's aim is, however, to provide a simple and ready means of ascertaining, with sufficient accuracy for practical purposes, the rate a train may be travelling at any time and between any points, simply with the aid of a reliable stop-watch. To this end he has worked out a table printed on a card that may be carried in the pocket. The calculations are based on a fixed distance of 200 metres. In the first column is given the rate in kilometres per hour corresponding to the number of seconds occupied in running that distance; in the second this time is given: where the speed exceeds 80 to 100 kilometres the distance is to be doubled and the speed as well; where less than 12 to 20 kilometres both are to be halved. On the same card a diagram is printed from which the speed for any distance between 100 and 400 metres may be ascertained at a glance. The horizontal lines represent kilometres per hour; the vertical, distances at every 5 metres, and the diagonal, the time observed. Suppose, for instance, a train ran 275 metres in 17 seconds, the speed in kilometres per hour would be found at once by laying a card with its left edge on the 275-metre vertical line and its top edge coinciding with the horizontal line cut by the diagonal representing 17 seconds, the rate corresponding to this would be given in the margin, and in this case would be 57·7 kilometres per hour. The chief use of this diagram, the Author states, is for gauging rates on light railways where there are no mile-posts, but more especially for testing the action of brakes. Its application is described in full in the Paper, and the results obtained compared with those worked out by formulas.

W. A. B.

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The Central London Railway.

(The Engineer, 4 November, 1898, p. 440 *et seq.*)

The length of this railway is 6½ miles, and the capital outlay £3,000,000. It consists between the stations of two circular tunnels 60 feet or so below the level of the streets, one for the up and the other for the down traffic. They are built of cast-iron segments, and are each 11 feet 6 inches inside diameter. Most of the excavation is through clay, consequently very little compressed air has been required in operating the shields. Few obstructions have been encountered except at the Bank Station, where numerous pipes and sewers were met with. At the stations the cast-iron cylinders are 21 feet 6 inches diameter, and are similarly built of rings of cast-iron segments. The platforms are 325 feet long. Access to the stations is afforded by lifts in vertical shafts and by staircases. The tunnel tubes are connected to the station by brick walls 3 feet thick.

The shields for the stations are 22 feet 10 inches diameter and 6 feet 10 inches long, and for the tunnels 12 feet 8 inches diameter and 7 feet long. They are formed of steel plates riveted together with a cast-iron ring inside, forming the cutting edge, and for the twenty-two hydraulic plungers to abut against in driving the shield forward by pressing against the last ring of tunnel segments fixed. The station shields are provided with a hydraulic cylinder for lifting the segments into position for bolting up.

For excavating part of the length, a machine has been used consisting of a dredger ladder 17 feet long, in which there is no front to the buckets, and of which the working end can be moved vertically, horizontally, or longitudinally. It is worked by an electric motor. When sufficient ground has been got out in front of the shield the latter is pushed forward by the rams and another ring of segments added to the tunnel inside the tail of the shield. The rate of progress has varied from two to four 20-inch rings per shift of 10 hours.

A. W. B.

The Albula Railway in Switzerland.

(Schweizerische Bauzeitung, 1898, p. 153. 2 Figs.)

As the main points of the narrow-gauge line to connect Thusis and St. Moritz have been settled by the Rhätischen Railway Company, and the design of the tunnel is decided, the following details are given :—

The line will be 39·25 miles long and is to cost £784,000. The maximum gradients occur between Thusis and Filisur, 2·5 per cent.; and between Filisur and Bevers, 3·5 per cent. The minimum radius is 393·6 feet. At the exit from the tunnel the line is

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5,963 feet above sea-level. The principal tunnel is 6,406 yards long, and will be for about 5,073 yards through granite and about 1,333 yards through calcareous slate and dolomite. The cross-section will be 215 square feet, the height 16·4 feet, and the width 14·7 feet. There will be also twenty-seven other tunnels with a total length of 9,184 yards. It will take 4 years to complete the long tunnel, upon which the preliminary work is now begun.

E. R. D.

The New Railway from Calatayud to Valencia.

(Revista de Obras Públicas, 1898, p. 323. Figs.)

The section from Segorbe to Sagunto of the Calatayud-Valencia railway was opened for service last April. The works have been long delayed, and finally came into the hands of the Central Railway Company of Aragon. The total length will be 186 miles, and the length of the section now opened is 20 miles, and will afford communication between Segorbe and the towns of Valencia and Barcelona. The works were designed by Mr. Ramon Garcia, y Hernandez.

The most important feature of the section just opened is the viaduct over the river Arguines, 72 feet high, it has seven arches, the centre one of 65·5 feet span, and the six others of 32·8 feet span, composed of rubble masonry in hydraulic mortar and faced with dressed stone. At present the rolling stock consists of six goods engines, 29·5 feet long, with six wheels coupled and a front bogie, weighing 43 tons empty and 47 tons loaded; details are also given of the tenders, carriages and wagons.

The permanent way has several features of interest. It is the first railway in Spain for which metallic sleepers have been used, the rails are of steel, of Vignoles section, 29·5 feet long, and weigh 62 lbs. per yard. The rail is supported upon a metal packing or chair with tapered base, and it is held in position by a single bolt and cramp. The railway is of the ordinary Spanish gauge, 5 feet 6 inches wide. The chairs are made in four patterns, with bases of different slant to suit curves, and thus permit the sleepers themselves to be always perfectly level. The types of chairs and clamps are marked 0, 1, 3 and 4, and are so arranged that the total of the figures for each joint should always equal four, whatever be the degree of curvature of the line. The sleepers are 8·85 feet long. The Author considers metal sleepers much more economical than wood, and cites instances where this view has been proved to be true in Europe.

E. R. D.

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Express Electric Locomotive, Paris-Lyons-Mediterranean Railway Company. AUVERT.

(Revue générale des Chemins de fer, 1898, p. 331.)

Since the end of 1897 the Paris-Lyons-Mediterranean Railway Company have been experimenting with an express electric locomotive upon the main line from Paris to Melun. This locomotive has about one-half the power of a standard engine, but is so arranged that its power can be increased to normal without altering the type. The power is obtained from accumulators carried in a special tender. This arrangement was made in order to experiment upon high-speed electric locomotives without incurring the expense of a special plant, and fixing conductors along the line. The problems to be solved have been somewhat complicated by the use of accumulators, but the Author points out that results obtained with accumulators can be still more easily obtained with conductors.

The locomotive is carried on three pairs of wheels of equal size, 3 feet 7¼ inches in diameter, of which two pairs are drivers, each being independently driven by a continuous-current motor. The total wheel-base is 19 feet 8¼ inches. The body is divided into five compartments, of which the back one is fitted for the driver, and contains all the necessary handles for the control of the motors, also the brake-gear for both hand- and compressed-air. The front compartment contains an air-compressor worked by a 5-HP motor, the air being used for the Westinghouse brake, the whistle, and the pneumatic starting-gear. Of the three remaining compartments, two side by side contain each nine accumulator cells, which serve for exciting the main motors, and furnish the current for the compression of air, lighting, &c. This current will also drive the locomotive at a speed of 2 miles to 4 miles an hour. The centre compartment contains a large liquid rheostat for making or breaking the current to the motors, and which also serves for its regulation. The current for the main motors is furnished by two batteries of accumulators of ninety-six cells each, carried on a special car behind the locomotive, and connected to it by four cable conductors.

Each of the main motors at 500 revolutions a minute (corresponding to 64 miles an hour) develops 300 HP. with 360 volts and 700 amperes, and the accumulators have a capacity of 1,000 ampere-hours at a mean discharge of 500 amperes. The accumulators on the locomotive itself have a capacity of 1,500 ampere-hours at a mean discharge of 500 amperes. The total weight of the locomotive is 43¾ tons, and of the accumulator tender 45 tons.

The working gears comprise mechanical, pneumatic, electro-pneumatic, and electrical arrangements, which control respectively the brakes, starting gear, automatic disconnector, starting rheostat, coupler, and starting rheostat for the air-pump motor. Suitable

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ampere- and volt-meters, seven in number, indicate the tension and intensity of the current.

Separate detailed descriptions are given of the starting-gear, in which by an electro-pneumatic arrangement the exciting current for the motors can be started, stopped or reversed; the speed-regulating rheostat; the automatic disconnector, by means of which the current is cut off from the motors when from any cause the resistance becomes abnormal; the coupler, which is so arranged that the accumulators and motors can be grouped and connected as desired; the accumulators, &c. The following section gives the rules to be observed in starting, running, and stopping the locomotive, both with and without the accumulator car.

Various trials of the locomotive have been made, in which the restriction of the speed at which current could be drawn from the accumulators without injuring them, was found to be a great drawback. The maximum load drawn, exclusive of the engine itself but inclusive of the tender, has been 147 tons, at a mean speed of 28 miles per hour, the motors being coupled in series. With the motors running in parallel, and the load 100 tons, the speed attained was 62 miles per hour. The electrical power absorbed by the locomotive was approximately 500 kilowatts, the effective power being about 611 HP.

The trials have fully verified the correctness of the design and general mechanical arrangements of the locomotive, and have proved the limit of power of the accumulators. Further trials are about to be made to determine exactly the relative coefficients to the tractive force, the resistance to rolling at various speeds, &c., information indispensable to establish on a certain footing any scheme of electric traction.

The Paper is illustrated by three Plates and two Figures in the text.

H. I. J.

An Express Locomotive with Brick Fire-Box. C. CORTEIL.

(Revue universelle des Mines, vol. xliv., 1899, p. 117.)

This engine, which has been built for working express trains on the Belgian State Railways, at an effective speed of 50 miles per hour upon inclines not exceeding 1 in 200, with a useful load of 250 tons, and on heavier gradients up to 1 in 66, lighter trains of 150 tons at 40 miles per hour, is the first passenger engine to which the Docteur brick fire-box has been applied. It has inside cylinders, four-coupled, 2-metre driving-wheels, and a leading bogie with four 980-millimetre wheels. The total length of the boiler is 7·55 metres, of which 1·55 metre is taken up by the smoke-box, 4 metres by the tubular body, which is 1·5 metre in diameter and contains 277 brass tubes, and the remaining 3 metres by the fire-box. This has a grate 3 metres long and 1·10 metre

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broad, giving a surface of 3·30 square metres enclosed in an inner box lined with fire-bricks 2 inches or 3 inches thick, arranged with a system of air-cooling passages opening above the level of the grate, the whole of the air required for combustion being drawn through these passages and so raised to a high temperature. The surface of the brickwork exposed to the fire is 10 square metres and that of the air-admission passages, collectively, 0·0675 square metre, the latter quantity being $\frac{1}{4 \cdot 19}$ of the minimum area of the chimney and $\frac{1}{149}$ of that of the grate. The heating surface of the boiler is 139 square metres. The steam dome is replaced by a cylindrical reservoir, 0·700 metre in diameter and 2·48 metres long, placed above the body of the boiler and reaching to the level of the top of the chimneys. The weight in running order is 46·96 tons, of which 16·445 tons are carried by the front driving axle, 15·935 tons by the hinder one, and 14·580 tons by the bogie; so that the useful adhesive weight is 32·38 tons, giving a tractive effort of 6,098 kilograms, while that required for drawing a train of 330 tons, including engine and tender of 80 tons on a gradient of 1 in 200, is 4,935 kilograms. The saving in first cost due to the substitution of fire-brick for copper in the fire-box is about £200 per engine, and the heating power is considerably increased. As applied in the goods engine of the Mogul type, No. 512 of the Belgian State Railway,[1] burning a mixture of $\frac{3}{4}$ dry slack with $\frac{1}{4}$ of coking coal, an evaporative effect of $8\frac{1}{2}$ to 9 parts of water per unit of fuel was realized. The lining is very durable; that of No. 512 has been used ever since July 1894, and its renewal can be effected by an ordinary bricklayer in 3 days, at a cost of less than £4.

H. B.

Combined Lever-and-Screw reversing Gear. P. GUEDON.

(Revue générale des Chemins de fer, 1898, part vi., p. 416.)

Reversing gear with a lever and sector presents numerous disadvantages, the principal one of which is that the changes of admission of steam or air are limited by the number of notches in the sector, and the most favourable degree of expansion cannot always be obtained. It presents, however, the advantage that the change of gear from one position to another can be quickly and easily effected. The admission of steam or air with a gear worked by screw and hand-wheel can be varied to any desired degree; but the change from forward to back gear is a work of some time, and, when frequently performed, becomes tiring to the driver.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 522.

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The Author describes a new reversing gear[1] introduced on the compressed-air motor-cars of the Compagnie Générale des Omnibus, which combines these two systems. The sector is made in two parts, and the upper part, in which the notches are formed, is capable of being moved on the lower fixed part. On this latter are bolted two brackets, which carry a screw and hand-wheel, and a gun-metal nut, fixed to the movable part of the sector, engages with this screw, the movement of the hand-wheel in either direction altering the position of the notches relative to the lower part of the sector.

In working, the lever is dropped into the nearest notch corresponding to the desired position of the reversing gear, and any further movement made by turning the hand-wheel, which is so arranged that the travel of the screw moves the lever to a position corresponding to the normal position of the next notch on the sector. Every possible position of the gear is thus provided for, and the advantages of the lever gear are at the same time retained.

In actual working an economy of 10 to 12 per cent. has been obtained, owing to the air being used with the most favourable amount of expansion. The additional cost of the gear is small, amounting to about £2 per set.

The article is illustrated by five sectional drawings of the gear.

H. I. J.

The Fehrmann Superheater. R. Schenkel.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes. 1898, pp. 452-454.)

Each element of this superheater consists of two concentric wrought-iron tubes, whose ends are suitably jointed; the steam circulates through the annular space between the tubes, and the furnace gases impinge upon the outer and inner surfaces of the compound tube. In the annular steam space a number of corrugated copper plates are placed, the natural spring due to the corrugations being such that the plates are held tightly against the outer and inner tubes. Alternate strips of the copper plate have the corrugations staggered, so that the steam is thoroughly mixed during its passage. The high thermal conductivity of copper as compared with iron makes it desirable for use in a superheater; unfortunately, however, it is unsuited to resist high temperatures and pressures. The arrangement of the Fehrmann superheater utilizes the high conductivity, but makes no demand on the strength of the copper at high temperatures. A. S.

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[1] A gear on this principle is shown in Heusinger von Waldegg's "Handbuch für specielle Eisenbahn Technik, Leipzig, 1882," Plate xxxiii. A similar device is due to the late Robert Stephenson.—Sec. Inst. C.E.

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Friction-Brake for Engine-Testing. C. CARIO.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1899, p. 2.)

This Paper describes two new types of brake for making tests of engines up to 150 HP. with bolt or rope-pulley flywheels placed in pits, and on which therefore the ordinary types of friction-brakes could not be used. When the flywheel of the engine is of the belt-pulley type, a single stout wooden beam is made to rest on the upper surface of the flywheel by means of two shoes hinged to the wooden beam. One end of a cotton strap is fixed to a point somewhere about the middle of the beam, the strap passes round the lower surface of the flywheel, over the pulley at the outer end of the brake beam, and the free end is adjusted by a screw and hand-wheel; the hand-wheel being placed at the inner end of the beam, which rests on the platform of a small weighing-machine. The platform of the weighing-machine is placed near the level of the engine shaft, and the pressure indicated by the weighing-machine, in conjunction with the dimensions of the apparatus, gives the necessary data for estimating the torque transmitted by the engine to the brake. Small wooden blocks are interposed between the cotton band and the rim of the flywheel. Water is used to lubricate the brake blocks and flywheel rim.

The special advantage of the apparatus is that it can be adapted to any size of flywheel within reasonable limits.

Another modification is described for a rope-pulley flywheel. Here the brake beam is made up of four separate wooden beams bolted together and lying horizontally, symmetrically disposed with respect to the centre of the flywheel, two of the beams lying above and two below the engine shaft, and a pair lying at each side of the flywheel. With this rope brake an engine of 150 HP., with flywheel 10 feet diameter making 90 revolutions per minute, was tested. The brake test lasted only a quarter of an hour, since it was only the mechanical efficiency of the engine that was to be investigated and not the steam consumption.

The Paper is illustrated with drawings of the apparatus.

A. S.

International System of Screw Threads. E. SAUVAGE.

(Revue de Mécanique, 1898, p. 407.)

An international congress was held at Zurich in October, 1898, for the purpose of arriving at an international system of screw threads, delegates from important engineering associations in France, Germany, and Switzerland being present. The congress

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adopted the system proposed by the Société d'encouragement pour l'Industrie Nationale,[1] with the following exceptions:—

(1) The part cut off at the top and bottom of the original triangles should not exceed one-sixth part of the height. The form to be given to the top and bottom is left to the manufacturer, but the congress recommends the adoption of a rounded profile.

(2) The series extends between diameters of 6 millimetres and 80 millimetres.

(3) The table of normal diameters is that proposed by the Société d'encouragement, with the exception that for the diameter 8 millimetres a pitch of 1·25 millimetre, and for the diameter 12 millimetres a pitch of 1·75 millimetre is adopted.

The name Système International, with the initial letters S.I., has been given.

A. S.

Bicycle Construction. HERMANN HALDICKE.

(Verhandlungen des Vereins zur Beförderung des Gewerbefleisses, 1898, p. 415.)

This article first gives the history of the discoveries and inventions which have brought the cycle to its present-day form. It then gives a description of the methods of manufacture of the various parts.

The frame is first considered, the proper proportioning of each member to its work being considered. The various methods of manufacturing the tubes are given. The connecting pieces for the tubes where rigidity is required are described, and the various methods of manufacture detailed—out of the solid, by casting, and by stamping and pressing out of the plate. The making of joints where rigidity is not required, that is, in pin joints, is next described, together with the most approved methods of fitting the frame together. The fork with its connection to the tube is then discussed. Next are mentioned the wheels, the methods of construction of the different parts, the nave, the spokes, and the rim, being fully detailed. Wooden rims are mentioned. Special attention is given to describing the accurate centering of the wheels. The different kinds of roller bearings are sketched, and the manufacture of the balls very completely described, together with the methods of ensuring their true spherical form. The driving-wheel and pedals with the chain are also discussed.

A few novelties are taken up at the end of the Paper, and shortly described, these being principally connected with different gearings.

The article is well illustrated throughout, and cuts are given of special machinery.

W. B.

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[1] Minutes of Proceedings Inst. C.E., vol. cxiv. p. 442.

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Slate Quarrying in the Ardennes. N. WATRIN.

(Les ardoisières des Ardennes, Charleville, 1897.[1])

In this work—which covers 332 pages, and is illustrated by 55 figures in the text and a map—the Author gives a detailed description of the extraction of roofing slate at the extensive quarries at Fumay, Rimogne, and Deville-Monthermé in the French Ardennes. These quarries, which have been worked for a long time, afford subsistence to more than 10,000 persons; the production being 140,000,000 slates annually, representing a weight of 55,000 tons, or nearly a quarter of the total French production of roofing slate. The industry began at a very early date. A charter confirming privileges granted to the quarrymen bearing the date of June 15, 1551, is still preserved, and it is probable that slate was quarried in the Ardennes in the fifth century. The slate is obtained from the base of the Cambrian rocks, and the industry has been successfully developed along the banks of the canalized River Maas. This development illustrates the importance of water transport for heavy and bulky material. The slate is wrought by underground mining on an extensive scale. Steam, hydraulic power, and compressed air are utilized for winding, pumping and drilling. Electricity is used for blasting and for signals, whilst telephones ensure rapid communication in the workings. Dynamite is used for driving levels and sinking shafts. The slate is obtained by making excavations, usually 16 yards long, separated by pillars 5 yards thick on each side of the main roadway. The width of these excavations is limited only by the termination of the bed, by unworkable material, or by the boundary of the concession. The height is equal to the thickness of bed workable. The pillars are pierced in places by airways, 4 to 8 yards wide, serving for ventilation, for drainage and for means of access. For blasting down the slate black powder is now but little used. Its place has been taken by compressed powder. The blocks broken down are in some cases of great size. In the Moulin-Sainte-Anne bed they are as much as 20 yards wide, 15 yards long and 1½ yard thick. Large blocks are subdivided with the aid of blasting powder; smaller ones are broken up by wedges. The pieces obtained weigh 100 to 160 lbs., and are carried by the miners to the wagons and brought to the surface. The Author gives details of the quarries, the methods of working, explosives used, haulage, drainage, ventilation, lighting and methods of underground surveying, the history and development of the various quarries, and the legal administrative and social conditions of the industry.

B. H. B.

[1] The original is in the Library Inst. C.E.

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Driving Levels with and without Explosives. A. FIRKET.

(Annales des Mines de Belgique, 1898, p. 183.)

At the Boverie pit of the Marihaye collieries a stone drift has recently been driven without explosives at a depth of 178 metres, through ground of substantially the same character as that encountered in 1893 in a similar drift at 140 metres, when machine-boring and blasting with dynamite were used. Apart from variations in the hardness of the rock owing to intercalated silicious bands on the ordinary coal-measure shale, the conditions were so nearly alike as to admit of a very close comparison of the two methods.

In the former instance, at 140 metres the level, measuring 1·80 by 1·70 metre, was driven with the Thomas drill and Nobel's dynamite, the machine served by two miners working two shifts of 9½ hours each daily. The length driven in 50 effective working days was 61·55 metres, of which 49·30 metres were in shale and 12·25 metres in hard beds (psammite), which is considered to be equivalent to about twice its thickness of shale, or 1·24 metre actual, or 1·48 metre computed on the basis of all shale per diem, while the average cost of wages per metre actually driven was 20·15 francs, or allowing for the retardation by the hard bands, 21·60 francs per metre.

At the 178 metres, using a "bosseyeuse" of 120 millimetres diameter of piston, and a somewhat larger section 1·90 metre by 1·80 metre, with two men driving in three shifts of 8 hours, the progress realized in 75 effective days' work was 58·70 metres (43·15 metres in shale and 15·55 metres in psammite), equal to 0·78 metre actual, or 0·99 metre computed as all shale, the wages charge being 41·30 francs per metre and 32·65 francs per metre respectively. Allowing also for the larger section of the machine-driven level, the cost of the smaller one comes out at 22·86 francs, or the speed of driving with the bosseyeuse is 71 per cent. of that of the boring machine and dynamite, and the cost in wages is 43 per cent. higher.

Notwithstanding the apparent disadvantages the Author considers that the use of the bosseyeuse is to be recommended in all cases in fiery mines, more particularly for opening out in the coal; and supposing compressing plant to be supplied for this purpose, its use in stone drifts would only lead to an increase in cost too small to be of importance when compared with the extra safety obtained and the smaller disturbance to the ground, which is not shaken in the same way as when high explosives are used.

H. B.

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The Dulait-Forget Electric Rock-Drill. J. SMEYSTERS.

(Annales des Mines de Belgique, 1898, p. 190.)

This drill, which has been used at the Courcelles-Nord colliery for cutting out a reservoir 56 metres long and 3 metres by 3 metres cross section, is driven by a rotatory electric motor by means of a flexible shaft, through gearing-wheels acting upon a shaft carrying a cam, which draws back the tool-carrier against the resistance of a coiled spring contained in the guide-box. This, when the cam passes off the tappet, throws the drill forward against the rock. The feed-motion is worked by hand, and the machine is mounted on the ordinary double-column stand. To ensure good working it is necessary to keep the flexible driving-shaft as straight as possible, as otherwise it heats and there is a considerable loss of power. In any case the ends of the shaft heat very easily, and careful and liberal lubrication is necessary. The progress as a rule is slow, as the ground (sandstone) is extremely hard, the average is about 10 centimetres per minute, and the drills are easily blunted, as many as four changes being sometimes required for a single hole of 1 metre deep.

The motor receives a direct current of 115 volts from a generator at the surface, 1,150 metres distant, or a circuit of 2,300 metres by a cable 20 square millimetres section, which on the way supplies the lamps at the onsetting place at the pit bottom, taking 22 amperes, leaving 12 amperes for the boring machine, or a total intensity of 34 amperes, or 1·7 ampere per millimetre of section. The line resistance is 0·921 ohm per kilometre, or 2·12 ohms for the whole circuit, with a fall of potential on the line of 25 volts equal to an expenditure of 305 watts. The work realized by the motor $12 \times 90 = 1{,}080$ watts = 1·47 HP. per 10 centimetres bored per minute.

H. B.

A Trial Boring for Coal on the Lower Rhine.

(Glückauf, 1898, p. 1005.)

At Elfriede, near Sinsen, in the northern part of the Westphalian coalfield, a boring for coal was carried to a depth of 2,200 feet in less than 2 months. The ground passed through consisted of 12½ metres of loose sand and marls, followed by grey marls and chalk, becoming flinty at 629 metres, when the percussive system, adopted after the loose surface measures had been penetrated, was abandoned in favour of the rotatory diamond crown. The lower greensand was reached at 658·6 metres, and the coal measures at 666·6 metres. A seam about 5 feet thick was passed through at 674 metres, at which depth the work was stopped. The hole was started with a diameter of 10½ inches

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at the surface, which was successively reduced to 9¼ inches at 12½ metres, 8 inches at 31·3 metres, 7 inches at 154 metres, 6 inches at 302 metres, and 5 inches at 503 metres, lining tubes being put in at each change of size. Below 503 metres no further tubing was required. The work began on the 20th August, 1898, and was finished on the 17th October, in which period two stoppages, caused by the breaking of the walking beam and a driving-shaft, together of 9 days, are included. The chalk marl, 616 metres thick, was bored through with the chisel in 40 working days, or an average of 15·4 metres per day, while with the diamond borer a speed of 44 metres in 5½ days, or an average of 8 metres per day, was realized. Making no allowance for the time lost by accidents, the average was 11·4 metres per day for the 59 days—20th August to 17th October—that the work was actually in hand.

H. B.

The Manganese Ores of Brazil. RIBEIRO LISBOA.

(Revue universelle des Mines, vol. xliv., 1899, p. 1.)

Deposits of manganese ores susceptible of economic exploitation are known to exist in the provinces of Matto Grosso, Sao Paulo, and Minas Geraes, but it is only in the latter that actual workings have been carried on. The principal localities are at Queluz and Miguel Burnier, near the line of the Central Railway of Brazil, about 320 miles from the harbour of Rio de Janeiro. The ore consists principally of manganite (M_2O_3 H_2O), with some pyrolusite (MnO_2) and other oxidized minerals in smaller and variable proportions, giving from 50 per cent. to 54 per cent. of metallic manganese and 15 per cent. of volatile matters. These minerals are found in thin veins in the crystalline schists of Queluz and Gaudarela, and in masses of considerable size and extent in the older stratified (Huronian) rocks, which are principally Itabirite—a slaty rock made up of specular iron ore and quartz—overlying limestone. These masses, from 6 feet to 7 feet thick, are included in the Itabirite, and follow the undulations of the strata, which are considerable, the dips ranging from 30° to vertical, and extend in a discontinuous line for some miles along the railway. The ore is won by open quarries with hand-tools, without explosives, but no regular system of working is observed, the faces being laid out at all heights up to about 16 feet apart. When broken it is carried by ox-wagons, or, in some cases, by Decauville railways laid on the incline, to inclined depositing platforms on the railway, whence it is carried in 12-ton truck-loads to Rio. Freights to England vary from 9*s.* by sailing vessels to 12*s.* by steamers. The total cost of the ore delivered in England is 57·340 reis per ton, which the Author thinks could by a better system of working be reduced to 47·840 reis. The value in

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England at 1*s.* per unit, the ore averaging 45 per cent. clay, is 45*s.* per ton, which, at the exchange of 6*d.* per milreis, gives a profit of 32·660 reis per ton. That these ores can be profitably exported is due to the great depreciation (about 400 per cent.) in the Brazilian currency, for with a rise to 1*s.* 1*d.* the margin is reduced below 2*s.* per ton. According to another authority [1] the export of manganese ores from Brazil has been :—

1894	1,300 tons to	Middlesbrough.
1895	5,490 „	„
1896	14,120 „	„
1897	8,800 „	Philadelphia.

While for 1898 it is estimated at 20,000 tons.

H. B.

On New Underground Pumping Engines for Mines.

B. Gerdau.

(Zeitschrift des Vereines deutscher Ingenieure, xxxiii., 1899, pp. 29–57.)

This is an account of several underground pumping engines that have been supplied to deep mines in the Westphalian coalfield and elsewhere by Messrs. Haniel and Lueg of Düsseldorf, among which are included examples of direct driving by steam sent down from the surface, as well as by hydraulic and electric transmission. The first of these is a two-cylinder receiver compound engine at the Hansa pit at Huckarde, near Düsseldorf, which is remarkable, not only for the great height of the lift, but for the manner in which a feeder about midway down is utilized for part of the work. The leading dimensions of the engines, which are placed 664 metres (2,079 feet) below the surface, are as follows :—

Diameter, high-pressure cylinder, 700 millimetres; low-pressure, 11,000 millimetres; air-pumps, 250 millimetres; plunger-rams, 105 millimetres; length of stroke, 1,000 millimetres; revolutions per minute, 60; water lifted 2 cubic metres (440 gallons) per minute 664 metres high.

The two cylinders are coupled at 90 degrees, and each has its own air-pump and two single-acting plungers placed back to back, their valves being controlled by a rocking shaft and rods driven from the main cross-heads. The water is raised from the sump of the shaft 238 feet below the engines, or 2,316 feet from the surface, by a lifting set worked by a small two-cylinder water-pressure engine, driven by a feeder piped down from the 333 metre level, giving 1,097 feet head and delivered into a well in the engine-room, whence it is drawn by the suction pipes of the air-pumps through the condensers and passed into the suction boxes of the main pumps under a pressure of about 2 metres, and is

[1] Stahl und Eisen, 1899, p. 48.

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finally forced to the surface in a single lift through a rising main 196 millimetres in diameter. The suction of the main pumps is so arranged that any excess of water from the driving column not required by the water-pressure engine can be passed in under the full pressure, but the amount has been so small that it has been used for other purposes in the mine. Steam is brought from the surface by a well insulated pipe of 175 millimetres diameter. The boiler pressure is about 5 atmospheres and that at the engines is nearly the same.

The principal objection to this style of engine is its great breadth. The engine-room is 120 feet long and 27 feet broad, and has been subjected to such severe pressure from subsidence in the ground that it has been necessary to strengthen the masonry and rebuild the engine beds, but in spite of these difficulties they have worked almost continuously for nearly six years.

A second example of steam-pumping plant is that at the Piesberg anthracite mine near Osnabrück, which has been recently stopped. This has two tandem compound condensing engines placed back to back, and an engine-room 128 feet long and 13 feet broad, together lifting 12 cubic metres (2,645 gallons) when making 60 revolutions per minute. The pumps are 275 millimetres diameter and 900 millimetres stroke, the lift is 180 metres (591 feet). On trial these engines developed 303·9 I.HP. for 264·2 effective HP. in water delivered, including friction in the pipes, with a consumption of steam, at 6·8 atmospheres effective pressure, of 7·92 kilograms per indicated, or 9·11 kilograms per effective HP. per hour. A very large underground engine now in course of construction, intended to lift 30 cubic metres (6,612 gallons) per minute about 400 feet, is also noticed. This is of the triple-expansion form, arranged as a double tandem, with two low-pressure cylinders, and is expected to work with only 7 kilograms to 7½ kilograms of steam per effective HP. per hour. The Author however considers that the danger of keeping such large engines under steam in mines is against their use, except under very special circumstances and at comparatively shallow depths.

Under the head of hydraulic transmission the Author notices several methods in use, particularly the duplex system, in which one engine at each stroke reverses the valve in an adjacent one, of which several examples are given. This however is considered to give no advantage over a simple reciprocating engine. The best results have been obtained by short-stroke rotatory engines, each working a single plunger and coupled by threes on the same fly-wheel shaft. Two installations of this kind have been supplied to the Rheinpreussen colliery at Homberg on the Rhine, each lifting 2 cubic metres (490 gallons) per minute 455 metres (1,960 feet). The power is produced by a compound engine with 760 and 1,200 millimetre cylinders and 1,000 millimetres stroke, with four 88 millimetre pressure pumps working up to 55 revolutions per minute. The underground engine has three power pistons of 105 millimetres and three plunger pumps of 157 millimetres of 800

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millimetres stroke and makes 60 revolutions per minute, giving a speed of about 315 feet per minute, which is probably higher than that of any hydraulic motor of the same power previously used. With 369·5 I.HP., producing a pressure of 122½ atmospheres in the driving column, equivalent to 333·25 HP. work, or about 90 per cent. in the pressure pumps, while the work in water lifted 250 litres (55 gallons) per minute against a resistance equal to 463 metres (1,519 feet), corresponded to 252 HP., or a duty of 68·5 per cent. of the steam-power employed. The pressure pipe is 105 millimetres and the return pipe 115 millimetres in diameter, the rising main of the pumps is 200 millimetres. Shortly after the erection of the first of these engines two out of three small surface pumping engines broke down and the water rose in the shaft to a height of 430 metres above the level of the hydraulic engines, which however continued to work without interruption for several days until the older engines were repaired and set to work again.

In the last section two examples of electric-driven pumping engines are given. The first, employed in brine pumping with a lift of 440 metres, equivalent to 528 metres of water, is driven by a continuous current motor making 215 revolutions per minute, which is reduced by two trains of spur gearing to 28 revolutions in the pumps—a disadvantageous combination due to the fact that the mechanical and electrical parts were supplied by different makers—while in the second both generator and motor are of the direct acting class. This plant, built in 1897 for Nos. 1 and 2 pits of the Zollverein colliery to lift 3 cubic metres (660 gallons) per minute 405 metres (1,328 feet), includes a two-cylinder compound marine engine of 450 to 500 HP. driving a flywheel dynamo with 20 poles, giving 50 alternations per second at 150 revolutions per minute, working up to about 300 kilowatts at 1,000 volts. The continuous current exciter in the same shaft develops 100 amperes and 110 volts, in addition to which a small exciter, driven by an independent steam engine, is used at starting until the main engines have got up to their proper speed and the main exciter takes over the entire work.

The current is conveyed down the pit by two separate cables, each having three insulated copper conductors of 180 square millimetres section. The conductors are divided partly to reduce the diameter of the cable and partly as a reserve. The underground pumping engine has two differential plunger pumps with rams of 127 and 180 millimetres diameter and 1,000 millimetres stroke, the motor forming the flywheel makes 62 revolutions per minute. The surface engine, making 142 revolutions per minute, develops 426 HP., while the pumps at 60·2 revolutions lift 3,050 litres (411 metres), equivalent to 278 HP. or 65·5 per cent. This, with a consumption of 7 kilograms of steam per I.HP., corresponds to 10·65 kilograms per effective HP. per hour, a rather less favourable result than given by the hydraulic transmission; and although the difference between the three systems is not very

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great when the engines are worked continuously, it is otherwise when they are only required for a few hours daily, in which case the loss by condensation in the pipes when steam is used may be as much as that of the steam actually used by the engines when at work. This is seen in the following comparative Table :—

Consumption in Kilograms per HP. Effective per Hour.	Working Continuously.	Working 12 hours Daily.	Working 6 hours Daily.
Engines pumping by rods from surface .	11 to 12	11 to 12	11 to 12
Underground steam-engines	10½	12½	16½
„ hydraulic-engines	10	10	10
„ electric-driven engines . .	10·65	10·65	10·65

The use of hydraulic engines is restricted by considerations of the resistance of the plungers to buckling strains, which should not be lower than that of the piston-rod, and this limit is about reached when 72-millimetre rams are used with a compound engine of 780 and 1,120-millimetre cylinders and 1,200 millimetres stroke. A higher pressure than 250 to 300 atmospheres at the surface offers no advantage in actual working.

H. B.

The Electrical Installation of the Blanzy Mines.

(Comptes rendus mensuels de la Société de l'Industrie Minérale, 1898, p. 202.)

This important plant, which has been started during the year 1898, in addition to lighting supplies power to a weaving-mill, and several motors, both on the surface and underground, by two separate lines of conductors. These will subsequently be increased to four lines, one serving the weaving-mill, a second the north pit, the third the other pits, and the fourth the compressors and the shipping port.

The central station contains three groups of alternators, two of 300 HP. each, and one of 700 HP. Steam is supplied by six short boilers of the MacNicol type without drums, having 215 square metres of heating surface, and grates of 5 square metres. They are worked with forced draught, and burn very inferior fuel, principally consisting of shale and dirt from the coal washery. The engines, by Willans and Robinson, of 300 HP. each, make 350 revolutions per minute, and drive the alternators by Raffard ring couplings. The 300-HP. alternators are of the Thury form with fixed armatures, developing 200 kilowatts at 5,000 volts, with a frequency of forty-eight complete alternations per second. The excitation consumes about 1 per cent., and the yield at full load is 92 per cent. The 700-HP. generator is also a Thury machine, slightly differing in detail, but giving the same

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proportional effect. The primary current is distributed by overhead wires, with the usual protecting arrangements at road-crossings. Transformers are placed at each of the secondary stations, reducing the tension to 125 volts for lighting and small motors, and to 700 volts for machines working underground. The more important of these motors are:—

(1) One of 65 HP. making 580 revolutions, working an endless chain haulage in the Saint Francois pit.

(2) A similar motor to the preceding, working a pump at the 257-metre level in the Magny pit.

(3) Two motors, one of 40 HP. and the other of 30 HP., working a main and tail rope haulage at the Magny pit.

(4) A 15-HP. motor, working a Mortier fan underground, giving 6 cubic metres of air per minute at 30 millimetres water gauge.

Among the smaller motors are those of the weaving-mill, one pumping feed-water at Galuzot, a distance of 5 miles from the central station, and another working an inclined plane in a quarry, which takes the full tension of the primary current.

The effective yield with the larger machines working continuously, such as the pump, is 44·4 per cent. in water lifted, and 70·8 per cent. for the transport proper between the shaft of the steam-engine and that of the electro-motor, but taking all classes, large and small together, it may be estimated at about 60 per cent.

H. B.

The Application of Röntgen Rays to the Examination of Mineral Fuel. J. DANIEL.

(Annales des Mines de Belgique, 1899, p. 3.)

If a piece of coal is examined by a pencil of X-rays the permeability is found to vary very considerably with differences in composition, the purely carbonaceous parts being freely traversed, while the non-combustible parts, shale, pyrites, &c., are practically opaque. This property has been utilized by Mr. H. Couriot, of the Ecole Centrale in Paris, for exhibiting the structure of coals, which, when photographed by the radioscope, show a more or less regular alternation of light and dark bands, the latter corresponding to the bands of shale, with at times irregular dark spots due to inclusions of pyrites. The Author has repeated these experiments with a coil giving an 8-inch spark with an independent commutator, the time of exposure with samples about 20 millimetres average thickness being one minute. The pictures obtained are given in seven plates, which represent various samples of coal, coke, and patent fuel, the pitch in the latter case being of the same transparency as the coaly matter. In order to obtain comparable results it is necessary that the time of exposure of the plate, as well as that in printing,

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should be strictly the same in all cases. For coals also it is necessary to present the sample edgeways, *i.e.*, with the planes of stratification parallel to the cathode rays, when the shale bands are shown in stripes varying with their thickness, while if placed on the flat a continuous band near the surface, even although very thin, may be sufficient to make the sample completely opaque. This direct method may be used when it is desired to keep a record of the structure of specimens which are intended for analysis, as for instance in the case of samples from core pieces obtained in boring for coal; but for ordinary use an approximate method of quantitative determination of the art is desirable. This the Author has attempted to obtain by exposing mixtures of pure coal and shale, in variable proportions, finely-powdered, and made as nearly homogeneous, in cubic paper boxes of 2 centimetres side, to the action of the X-rays. The resulting radiograph gives a scale of tints varying from a pale gray to deep black, in proportion to the amount of shale present. These are perfectly uniform in character, but up to the present time it has not been found possible to establish a standard method of investigation by this system. Another plan communicated to the Author by Mr. Couriot, dispensing with the use of photography, consists in exposing the finely-powdered coal to the action of the cathode rays in a wooden box, whose plan is a right-angled triangle, with the shorter sides 450 millimetres and 900 millimetres and the hypothenuse rather more than 1 metre long. The latter, which is the observing side, is covered with a fluorescent screen divided into $\frac{1}{2}$ millimetres, the illuminating pencil enters from the long side of the right angle, and the point on the scale where the fluorescence ceases to be apparent, depending on the thickness of the interposed coal, which may be anything between 0 to 450 millimetres, is a measure of its purity. The radioscope may be applied in a similar manner for examining the quality of graphite in drawing pencils through the cedar mounting and the carbons of arc lights and dynamo brushes. The Author has also found that malleable iron plates up to 10 millimetres thick show a certain permeability when examined with the fluorescent screen, and suggests that this may be of use for detecting internal flaws in plates up to 20 millimetres thick by examining them on both sides. Some experiments have also been made with gunpowder. The nitre and sulphur are completely opaque, while the charcoal is transparent. Two samples of nitro-cellulose, giving 189·6 and 205·4 cubic centimetres of nitrogen bioxide, when analysed, were perfectly transparent.

H. B.

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Petroleum Industry of Russia. N. CHERKASSOV.

(Morskoi Sbornik, January, 1899, p. 149.)

In a previous article on petroleum fuel for vessels of the Russian Navy and Volunteer Fleet,[1] the Author dealt with petroleum as a fuel only; he now considers it in its relation to the industry of the country. He first gives a general description of the petroleum-producing districts—four on the Apsheron Peninsula near Baku, and one near Grozno, on the northern slope of the Caucasus, on the Petrovsk-Vladikavkas Railway. He then gives statistics of the yield of petroleum, showing a rapid increase from 297,000,000 poods (4,800,000 tons) in 1894 to 500,000,000 poods (over 8,000,000 tons) in 1898. In 1897 it was 15,000,000 poods (242,000 tons) more than the entire yield of the United States of America. Only about 20 per cent. of the total yield comes from fountains—*i.e.*, boreholes delivering above the surface. Only about 5 per cent. of the petroleum-producing firms in Baku are Russian, and of late years foreigners have proved particularly eager purchasers of petroleum sites and factories. The average depth of the boreholes in 1897 was 128 fathoms (896 feet), and it is very slowly increasing. The greatest yield is obtained from depths of 180 fathoms to 230 fathoms (1,260 feet to 1,610 feet), and it is from these depths only that the oil rises in fountains above the surface. No diminution of yield of the boreholes has yet been observed. There are numerous works at Baku for the manufacture of lamp-oil or kerosene, lubricating oil, benzine, and asphalt. The Author deals with the produce of the different works, with exports, railway freights, &c., and shows how the producers have, by combination, driven up the selling prices of petroleum to four times the cost of its production. As the quantity of astatki produced is not equal to the demand, it is increased by the admixture of crude petroleum. The Author then again deals at length with his scheme, propounded in his previous Paper, for organizing the supply of petroleum fuel for the Navy and Volunteer Fleet, calculating that it could be supplied in the Black Sea at 11 kopeks to 12½ kopeks per pood (0·8*d.* per gallon), and in the Baltic at about double that price.

C. H. M.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxv. p. 433.

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On the Utilization of Coal-Dust and Slimes.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1899, p. 127.)

In the Saarbrücken colliery district considerable inconvenience has been experienced from the accumulation of fine coal-dust separated by dry sifting as well as from the mud deposited in the clarifying ponds of the coal washeries, as the methods of dust firing hitherto proposed, which require the fuel to be artificially dried, have not proved to be practically available. A new method —that of Messrs. Bechem and Post—has lately been introduced, which dispenses with any preliminary treatment, the dust being taken directly from the screens and the pond slimes when only superficially dried. In this condition the former contain from 26 per cent. to 28 per cent. of ash and 7½ per cent. of water, and the latter 30 per cent. of ash and 19 per cent. of water. These can be burned in Lancashire boilers by an air blast introduced under the grate through a water "pulverizer" or trompe worked at a pressure of not less than four atmospheres, the velocity of the air current being sufficient to set the bed of fuel in motion and burn the finely divided carbonaceous matter while in suspension, giving a large body of flame, while the grate bars are scarcely red hot. The water draining back through a collector in the ash pit may be used for condensing purposes or for feeding boilers. Owing to the large amount of incombustible material the labour in stoking and cleaning fires is about double that required with ordinary coal, and if a natural head of water is not available a special force-pump must be provided to give the necessary pressure, but in spite of these disadvantages the saving in cost, owing to the nearly waste character of the fuel, is very considerable, the cost per ton of producing steam at atmospheric pressure being given as follows:—

Fuel.	Round Coal.	Washery Slimes.
Cost of boiler and accessories, with 52·6 square inch heating surface	£350	£412 10*s.*
Steam production in 24 hours	20·97 tons.	19·15 tons.
Cost of fuel per ton	8·6*s.*	2·0*s.*
Evaporation per unit	7·0	4·11
Maintenance and depreciation per ton of steam	0·19*s.*	0·25*s.*
Cost of water	0·04*s.*	0·04*s.*
Fireman's wages	0·14*s.*	0·31*s.*
Cost of fuel	1·23*s.*	0·49*s.*
Total cost	1·60*s.*	1·09*s.*

or a saving in cost of 31·9 per cent. When third-class slack of the evaporative power of 5·8, costing 6·4*s.* per ton, was substituted for the better coal given above, the saving was 26 per cent.

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Comparative trials made at the Malstatt Waterworks, Saarbrücken, showed that the steaming power of the boilers was much improved, the hourly production of steam per square metre of heating surface being increased from 12·22 kilograms with round coal to 18 kilograms with dry dust coal, the evaporative factor of the former being 8·05 and of the latter 4·735, while the consumption was in the proportion of 100 to 230. The slime can either be burned alone, in which case it must be slightly damped before firing, or mixed with dry dust. The latter method seems to be preferable.

H. B.

On the Determination of Carbon in Cast Iron and Steel.

ROZYCKI.

(Revue universalle des Mines, December, 1898, p. 300.)

According to the Author determinations of carbon in cast-iron or steel may be made in less than an hour, and in more refractory alloys, such as ferro chromium, in about 2 hours by a method of direct combustion without previous removal of the iron by solution in metallic chlorides, as is usually done. The metal is pulverized or reduced to very fine shavings, and a weighed quantity of 0·25 gram for ferro chromium or 2 grams to 3 grams for steel is intimately mixed in a porcelain mortar with 20 grams of pure alumina. The mixture is placed in a porcelain boat 160 millimetres long and 25 millimetres broad in a porcelain tube, connected in front with a short tube of hard glass containing cupric oxide and an absorption apparatus containing 100 cubic centimetres of a solution of mixed potash and baryta water, and behind with a tube supplying pure dry oxygen. The combustion is done in the usual way, the tube containing cupric oxide being first rapidly heated, and then the part of the main tube containing the assay is brought to a bright red heat, a constant flow of oxygen being maintained for a period varying with the nature of the metal from 35 minutes to about 1½ hour. The carbon dioxide formed is collected in an insoluble form as barium carbonate, which is subsequently decomposed by acid, and the gas is determined volumetrically. No special reason for adopting this indirect method instead of following the ordinary method of absorption in potash and direct determination of the carbon dioxide by increase of weight in the absorption apparatus is given. Probably the latter method would be preferable.

H. B.

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The Gröndal Dellwik Magnetic Concentrator. E. PRIMOZIGH.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1899, p. 51.)

At Pitkäranta, in Finland, magnetic iron ores containing sulphides, such as copper pyrites and zinc blende, are now successfully treated by a process of magnetic separation, in which, differing from former methods of the same kind, the material is treated wet. The ore, containing only 20 to 25 per cent. of iron, is broken by a rock-breaker and ground to powder (0·5 to 1·0 millimetre) in a mill formed of a watertight cast-iron drum, lined internally with chilled cast-iron plates, and partly filled with cast-steel balls. The ore in lumps of the size of the fist is fed in through a hole at one end and carried out by a stream of water at the other end. Mills 1·75 metre in diameter and 0·8 metre long grind 50 tons of moderately hard ore in 24 hours with an expenditure of 8 HP.; but for very hard material they are larger—2 metres diameter and 1 metre long—and the output is only 30 tons. The only parts requiring renewal are the linings and the grinding balls; the former last for about 15 months, and the waste of the latter is at the rate of 15 kilograms per 100 tons of ore. The essential elements of the separating machine are the two rotating cylindrical parts known as the separator and collector. The former is made up of four ring-shaped electro-magnets connected to a central shaft and separated by brass rings at the ends. The collector is a wooden drum carrying eight concentric series of soft iron points. The stream of ground ore and water is led over the top of the separator, which takes up the magnetic particles, the other minerals passing away with the water. These particles are in their turn removed by the attraction of the iron points on the collector, which are temporarily magnetized by induction in passing the electro-magnets, and fall off into a collecting-box, when the magnetic influence ceases. The separator requires about ½ HP. to drive it, and a magnetizing current of 8 amperes and 35 volts. There are no intermediate products. The waste contains 1 to 1½ per cent. of magnetite, and the finished product 65 to 71 per cent. of iron, the concentration being the same whether the raw materials contain 18 or 40 per cent. of iron. According to the nature of the latter the amount treated is from 25 to 50 tons in 24 hours. The finely-divided magnetite is prepared for the blast furnace by pressing it damp in a briquette press, and subjecting the pressed blocks to a clotting heat, 700° to 800° C., for a short time, or by pressing it with a mixture of 3 to 5 per cent. of lime and exposing the bricks to the air for about a fortnight. A press taking 6 HP. turns out more than 60 tons of briquettes in 24 hours. The cost of working the process at Pitkäranta during the period January to September, 1897, was about 11*d.* per ton of rough ore treated. According to the Author's estimate the power required for a plant capable of treating 150,000 tons annually would be from 125 to 150 HP. and the cost £6,500. H. B.

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The Application of Hot-Blast in the Bessemer Process.

J. WIBORGH.

(Jernkontorets Annaler, 1898, p. 257.)

It has been observed that Bessemer converters, blowing iron of the same composition, work somewhat better in summer than in winter—a result that the Author considers is partly due to the difference in temperature of the blast at its admission to the converter, although this difference does not exceed 50° C. It is therefore probable that with a more decided increase up to 400° C. or 500° C. much hotter blows would be realized, and iron considerably lower in silicon could be used, with less wear in the tuyeres and a smaller loss on the weight of the charge. For this purpose it would be necessary to employ a firebrick stove of such capacity that the air passing through it during the time of blowing —about 10 minutes—may only lower its temperature by about 100° C.—from 500° C. to 400° C.—and this need not be very large. The dimensions proposed for converters blowing different weights of charges are given as follows, for a consumption of air of 300 cubic metres per ton at atmospheric pressure at the freezing point, corresponding to 343 cubic metres at 1,000 millimetres pressure and 450° C., and a velocity of 4 metres per second:—

—	Diameter.	Capacity.
	Metre.	Cubic Metres.
For an 8-ton converter .	1·70	13·6
„ a 6 „ „ .	1·45	10·2
„ a 5 „ „ .	1·35	8·5

The height in all cases is the same, namely, 6 metres.

At first sight it would appear that the increased volume of blast per unit of time might require either an increase in the larger section or of the blowing power in order to complete the blow in the required time, but this the Author thinks would be compensated by the more rapid combustion, as it is known from the researches of Tamm and Snelus, that at the beginning of, and sometimes all through, the blow, air passes through unconsumed, especially when the temperature of the metal is low or the bath shallow, and as such waste would be prevented by the hot blast, less air would be required. The amount of heat contributed by the blast at 450° C. is 41,800 Centigrade units per ton, which, taking the specific heat of melted cast-iron at 0·3, corresponds to a rise in the temperature of the bath of 145° C., or the equivalent in heating power of about 0·5 per cent. silicon or 0·75 per cent. phosphorus. H. B.

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On the Durability of Ingot Moulds for Steelworks.

O. SIMMERSBACH.

(Stahl und Eisen, 1899, p. 10.)

In the manufacture of cast-iron ingot moulds it is necessary to use the strongest possible foundry metal, *i.e.*, one containing a sufficiency of carbon with the least proportion of prejudicial constituents, the limits established by practice being somewhat as follows:—

Silicon	1·5 to 3·5 per cent.
Manganese	0·6 to 1·2 „
Carbon	3·5 to 4·4 „
Sulphur	0·075 per cent. maximum.
Phosphorus	0·120 „ „
Copper	0·125 „ „

The carbon should be present mostly as graphite, but of a fine grain and evenly distributed. Manganese is principally valuable for fluxing sulphur in the coke used in re-melting, and, therefore, should be increased when the fuel is bad. The limits given for sulphur, phosphorus and copper cannot be safely exceeded. Silicon may vary within wide limits, supposing it to be derived from the materials of the blast furnace charge. It is, however, different when, in consequence of bad working, silicon is taken up from the coke ash or the lining bricks of the cupola, which results in the irregular separation of graphite in patches, giving castings of very small durability. The worst constituent is, however, sulphur, metal containing 0·1 per cent. being below the first class, while with 0·15 per cent. it is too red short to stand the heat of the molten steel without breaking.

Arsenic is somewhat similar in effect to sulphur, and according to the Author, about one-third of any arsenic that may be present in the ore passes into the blast furnace slag, the remainder being reduced, as no trace of it is ever found in the waste gases. If, therefore, this element be present, it should be taken together with the sulphur, and the maximum of 0·075 per cent. fixed for the two conjointly. The limit given for phosphorus is about the highest permissible, moulds with 0·187 per cent. and 0·217 per cent. having stood very badly. As examples of the composition of moulds of good quality the following analyses are given, the first of these having lasted for nearly 250 casts:—

—	I.	II.	III.	IV.	V.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silicon	2·650	1·660	2·800	2·820	2·160
Manganese	1·000	0·550	0·830	0·830	0·730
Phosphorus	0·064	0·054	0·120	0·120	0·060
Sulphur	0·061	0·043	0·040	0·040	0·050
Copper	..	0·072	0·065	0·065	0·120
Carbon	..	3·450	4·400	..	..

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The durability of the mould is also influenced by properly proportioning the thickness to the weight of the casting. The following figures give the usual German practice:—

Weight of Mould.	Thickness.
7 cwt.	60 to 50 millimetres.
10 to 14 ,, ...	65 to 55 ,,
14 to 20 ,, ...	70 to 60 ,,
20 to 30 ,, ...	85 to 75 ,,
30 to 40 ,, ...	90 to 80 ,,
2 to 3 tons	105 to 95 ,,
3 to 6 ,, ...	120 to 110 ,,
6 to 10 ,, ...	140 to 130 ,,
10 to 13 ,, ...	180 to 165 ,,

In English works they are usually made somewhat thicker.

H. B.

Microscopic Structure of Gold Alloys.[1]

THOMAS ANDREWS, F.R.S., M. Inst. C.E.

(Engineering, 28 October, 1898, p. 541.)

An alloy of 99·8 per cent. of gold and 0·2 per cent. of bismuth was examined microscopically. The gold-bismuth alloy was found to be not homogeneously dispersed throughout the mass, but had locally disposed itself along the line of crystalline junctions of the large primary crystals of gold in an irregular manner. The normal crystallization had been in many places distorted. The result of each crystal of gold being thus surrounded by a mesh-work of gold-bismuth alloy, was that the physical properties of the metallic mass were altered, and the alloy, instead of being, like gold, ductile and pliant, was exceedingly brittle and of low tensile strength. These well-known properties of a gold-bismuth alloy are due rather to this cause than to the previously-held theory of an allotropic modification of gold occurring in the presence of bismuth. A single crystal of gold separated from the alloy displayed all the characteristics of pure gold. Alloys of gold with lead, silicon, tellurium and potassium were examined, and exhibited somewhat similar characteristics of segregation. These experiments seem to negative the theory that such alloys are a metallic solution of the alloying metal in gold. They also indicate the manner in which the electric resistance of metals may be affected by the presence of alloys, microscopically interspersed as enveloping membranes amongst the ultimate particles of the metals.

A. P. H.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxv. p. 428.

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The French Cruiser "Guichen."

(Le Génie Civil, vol. xxxiv., 1898, p. 92.)

The first-class cruiser "Guichen," constructed at St. Nazaire by the "Société des Ateliers et Chantiers de la Loire," is the most powerful yet built for the French Navy, her engines developing 24,000 HP., the "Dupuy-de-Lôme" and "Carnot" developing respectively 13,000 HP. and 15,000 HP. The normal power to be developed on a 24 hours' run is 14,500 HP.

Unlike other cruisers, she carries no side armour, the engines, boilers, &c., being covered by a steel protective deck 3·15 inches thick, raised at the centre to 31½ inches above, and extending 5 feet below, the water-line. A watertight bulkhead prevents water from reaching the portion protected by this deck should the vessel be struck outside its limits. The turrets are protected by armour 6¼ inches thick, and shields of special steel 2¼ inches thick are provided for protecting the gunners. The armament consists of two 6¼-inch and six 5½-inch guns, and six 1·85-inch quick-firers.

The principal dimensions are:—

Length between perpendiculars . . .	436·0 feet.
Width at water-line	55·5 „
Depth	23·6 „
Displacement	8,300 tons.
Speed with natural draught	20 knots.
„ „ forced draught	23 „

Three sets of triple-expansion engines with four cylinders each give a total of 24,000 HP. at 125 revolutions. Piston-valves are fitted to all the cylinders, and the valve gear is on Marshall's system. Two sets of air-pumps are independently driven, and a centrifugal pump provides the circulating water for the condensers.

The boilers, of d'Allest type, are arranged in two groups fore and aft of the engine-room. Each group is divided into three compartments by watertight bulkheads, each containing two rows of three boilers, or thirty-six boilers in all, the working pressure of which is 213 lbs. The total grate area is 1,600 square feet, and the heating surface of the furnaces 8,662 square feet. Ten ventilators supply the necessary air for the stokeholes, and the vessel is provided with four funnels.

The total cost, exclusive of the guns, was £583,333 sterling.

H. I. J.

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New German Torpedo-Boats. DENNINGHOFF.

(Mittheilungen aus dem Gebiete des Seewesens, 1899, p. 77.)

Six Schichau torpedo-boats, and two from the Germania shipyard, were commissioned for the 1898 manœuvres. The boats from both builders are practically identical, and steam 25 knots. The Schichau boats are 48·2 metres (158 feet) long, have 5·1 metres (16·7 feet) beam, draw 2·75 metres (9 feet) aft, and displace, with all on board, 155 tons. Modified Thornycroft boilers are fitted, which is a new departure, with triple-expansion engines indicating 1,800 HP.; the armament consists of one 5 centimetre (1·96 inch) quick-firing gun, and one 8 millimetre (0·31 inch) machine-gun.

Six torpedo-boat destroyers have been ordered from Schichau; they are to have twin screws, water-tube boilers, and are to displace 300 tons.

W. B.

The Coaling of Sea-Going Vessels. THEODOR NOVGTNY.

(Mittheilungen aus dem Gebiete des Seewesens, 1899, p. 17.)

The various methods of rapidly coaling warships and merchant vessels are discussed. When coal is transferred from depot or lighter to ship by carriers the load carried by each cannot for continuous work be economically increased above 25 kilograms (55 lbs.), or the lead much beyond 50 metres (164 feet). In the case of loosely-heaped coal, which can be got with a shovel, a man can load about 900 kilograms (17¾ cwt.) into baskets or vehicles for transport. With a lead of 50 metres the coal carried per man will be about 450 kilograms to 900 kilograms per hour. It may be stated generally that a man can trim about 1·5 ton of coal per hour, though in cramped bunkers his capacity will be less.

W. B.

The Postal Arrangements on the North German Mail-Steamer "Kaiser Friedrich."

(Archiv für Post und Telegraphie, 1898, p. 655. Figs.)

The s.s. "Kaiser Friedrich," recently put on the Bremen-New York route by the North German Lloyd, was built by Schichau of Danzig, and, though a little smaller than the "Kaiser Wilhelm der Grosse" of the same line, is as large as the principal fast mail steamers afloat, being 580 feet long, 64 feet wide, and 41 feet deep, with 12,500 tons register. Her draught is 28 feet and total weight 17,000 tons. The engines develop 25,000 HP. and an average

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speed of 21 knots is attained. Details are given as to the general arrangement of the spaces occupied by passengers, officers and crew. A particular feature is that in most of the first and second class cabins the port-holes can be left open in almost any weather, and at night or in stormy weather the fourteen water-tight doors in the bulkheads can be closed without interfering very much with the traffic in the vessel. The space allotted to the postal business is behind the boiler-room on the starboard side, and a plan and sections are given. The postal service room is on the main deck and below it the sorting room for printed matter, and on the lower decks the parcel rooms; there are special stairs and a lift from the orlop deck to the promenade deck. The through traffic bags are separated from those which require sorting. The fittings of the sorting room are described and details given of the method of dealing with the correspondence. It might appear that the position of the postal department so far aft and so near the shaft tunnel would not be satisfactory, especially if the officials were not good sailors, but from actual experience this objection does not seem to arise. Special stress is laid upon the novel arrangement of the various departments in a vertical plane, and it is stated that the use of the lift permits the work to be dealt with quite as readily as in the commoner case, where the departments are placed side by side on the same deck.

E. R. D.

Breech-Blocks for Quick-Firing Guns.[1] GEORG KAISER.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1898, p. 517.)

The Author describes in detail, with the aid of numerous sectional illustrations, the Skoda breech-block, adopted by Austria-Hungary for 12 centimetres (4·68 inches) and 15 centimetres (5·85 inches) ship and coast guns, the Befors breech-block in use in the Swedish artillery, the Nordenfelt breech-blocks, 1895 and 1897, and the Canet breech-block, 1896.

W. B.

Range-Finders. NIESIOLOWSKI-GAWIN.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1898, p. 827.)

The Author first considers the accuracy required in measuring distances for infantry and artillery purposes. He divides range-finders into three classes, according to the auxiliary science called in as aid. These auxiliary sciences are acoustics, geodetics, and

[1] Supplement to the second edition of the Author's book "Verschlusse der Schnellfeuer-Kanonen."

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optics. Those instruments based on geodetical principles are most important, and depend on the solution of a triangle whose base is small in relation to the height, the height being the range required.

In the instrument of Paschwitz, 1870, the base of the above-mentioned triangle is a constant, and what is measured is practically the parallax angle. By the use of this instrument a range can be determined in 4 minutes and with an error of 2 per cent. at a distance of 5,000 metres to 10,000 metres (5,500 yards to 11,000 yards). With a variable base and constant parallax angle the two instruments most worthy of notice are those of Roksandic and Souchier. These instruments are similar in principle to the sextant, the mirrors, however, being in fixed positions. In using Roksandic's instrument the range is simply fifty times the length of the base, and can be found in from ½ minute to 1½ minute, the degree of accuracy being within 3 per cent. The base of the triangle may be vertical, as on a coast with high cliffs. In connection with this case the Author goes fully into the corrections for the curvature of the earth and for refraction. The base line, instead of being set out or measured, may be contained in the instrument itself, in which case two telescopes may be used, one at each end of the base, or one telescope with mirrors either fixed or movable.

The range-finder of Barr and Stroud is the best instrument of this description, and, indeed, the best of all range-finders up to the present. In it the telescope is in the centre of the base, with mirrors disposed symmetrically at each end and the centre. There is also between one end mirror and the centre a deflecting prism, and it is the application of this prism which constitutes the great improvement effected. With a base of 1½ yard the error in a range of 3,000 yards is 1 per cent.

The range-finders based on optical principles are also dealt with. One of the most important of these has already been described in these abstracts (see vol. cxxxiv. 97–98, pt. iv).

The Paper contains very full reference to the literature of the subject, and is well illustrated.

W. B.

The Design and Armament of Modern Ring-Forts (Gürtelwerke).

KARL ONTL.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1898, p. 538.)

Each ring-fort (Gürtelwerk) should be an impregnable position in the chain of defence, and to this end must have an infantry garrison and an armament of light guns. By means of the heavy guns mounted in it, it keeps the enemy at a distance and engages his artillery. By a flanking fire it protects the space intervening between it and the next fort.

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The Author traces the change in design since the beginning of the last decade, necessitated by the advance in siege artillery, and especially by the introduction of rifled mortars.

The effect of modern mortar-batteries acting against the older types of fort is considered in detail and the following recommendations made:—

(1) All heavy guns should be protected by armour or placed in casemates.

(2) The means of communication between the various batteries must be so protected as to withstand a heavy bombardment, and a number of outlets on to the wall should be provided.

(3) The batteries flanking the surrounding ditch should be protected against heavy mortar fire.

(4) All important positions in the work should be so arranged that no two or more are in any one line of fire.

(5) The work should be so designed that the enemy's projectiles will strike at acute angles.

(6) The garrison accommodation should not be arranged under the heavy guns, but so that it may be as quiet as possible.

(7) To minimize the action of high explosive shells the batteries should be roofed with concrete or stone paving.

The Author insists strongly on the necessity of a powerful armament, and in particular on the value of flat trajectory guns as against mortar and howitzer.

Illustrations are given of a fort of the older type, and designs for a fort in accordance with the Author's views.

W. B.

The Explosive Action of Rifle-Bullets.

ALBERT EDLER V. OBERMAYER.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1898, p. 361.)

Following on his Paper, "Uebersichtliche Darstellung der optisch-photographischen Untersuchungen der durch bewegte Projectile in Luft erregten Vorgänge,"[1] the Author describes the experiments conducted since 1864 to determine the effect of high-velocity small calibre projectiles on the human body, and in particular certain investigations with plastic clay as a target.

Upon soft inelastic bodies, and on fluid or semi-fluid bodies, small high velocity projectiles have an explosive effect, breaking in their passage ragged holes ten or twenty times their diameter. The action has been variously explained as being due: (*a*) to the entrance of air into, or the generation of expansive gases in, the shot channel; (*b*) to the melting or deformation of the projectiles; (*c*) to regular or irregular rotation of the projectile, and to the

[1] Minutes of Proceedings Inst. C.E., vol. cxxxi. p. 452.

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centrifugal force of particles thrown off from it; (*d*) to hydraulic pressure; (*e*) to transference of velocity from the projectile to particles of the body passed through.

As regards (*b*), when lead bullets were fired against iron or steel plates with high velocities sufficient heat was generated to melt them, but in passing through soft bodies it was found that their temperature did not rise above 65° C.

The Author's Paper already referred to shows that the air carried along by a projectile is small in quantity, and is left behind in passing through the slightest obstruction. Further, as in soft bodies, the temperature of the bullet is under 65° C., it is quite improbable that sufficient water vapour could be generated during its passage to account for the explosive action observed.

With regard to the centrifugal force imparted to surrounding particles of the body passed through by the rotation of the projectile, it was shown that the explosive action was fully apparent in a slab of plastic clay only 60 millimetres (2·34 inches) thick, in passing through which the bullet only turned through about 90°, and further that the rotary energy is but a small fraction, approximately 0·6 per cent. of the total energy of the projectile.

By means of numerous experiments, such as firing through boxes and bladders, open and closed, and filled with fluids and semi-fluid substances, the hydraulic pressure (in distinction from hydrostatic pressure) set up by high-velocity projectiles, was shown to be considerable; the containers were broken open, and in one instance, though the figure is not given as absolutely reliable, a pressure of 24 atmospheres was measured.

Details are given of experimental shots through a number of plastic clay slabs of various thicknesses placed singly, and also two or three close together. The slabs were in some cases protected in front by thin plates of zinc, and in other experiments cylindrical boxes filled with clay were used. In the case of the slabs, the projectiles made holes many times larger than their diameters, and in passing through the cylinders threw out comparatively large volumes of clay.

Summing up, the Author states that explosive action only occurs in inelastic bodies, and when the particles of the body struck are sufficiently yielding to gather considerable velocity from the projectile. With enclosed bodies the force of the explosion is determined by the size and shape of the covering and by the length of the shot-channel. Explosive action demands a certain velocity, probably about 240 metres per second (787 feet per second).

The Paper is illustrated by 38 figures, and there are references to other works on this and allied subjects too numerous to give here.

W. B.

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The Electricity Works at Arosa.

(Schweizerische Bauzeitung, 1898, p. 179. Figs.)

Arosa is a well-known place of resort in the Alps at a height of 5,904 feet above sea-level. Since the summer of 1893 the village has been supplied with water, and the sewage is carried away by a system of canals discharging in the swift-running Plessur. In the winter of 1895–96 it was decided to erect a water-power electric-lighting plant, and the Oerlikon Machine Works formed a Company, on the basis that each consumer should take up a share to the value of 48*s.* for each 16-candle-power lamp installed on his premises, the actual price for current to be fixed at the end of the first year. The contract was signed the 9th April, 1897, work began in May, and the plant was set to work in November, 1897, and has worked well ever since. A weir was built across the stream called the Plessur, and a reservoir formed with about 42,380 cubic feet capacity; the fall in the river between this point and Reïtland, at a distance of 4,592 feet, is about 384 feet. An open canal was out of the question owing to frost, so a pipe line was adopted 21·45 inches diameter. With a delivery of 12·7 cubic feet per second, and 75 per cent. efficiency of the turbine, about 312 HP. is developed on the turbine shaft. The machine room is large enough for 3 units, of which only two are at present installed; each gives 110 HP. on the turbine shaft at 600 revolutions per minute. The turbines are by Escher, Wyss & Co., and are coupled direct to the dynamos, which are of the three-phase type, giving 2,100 volts per phase and 3,600 volts total. This type was chosen owing to the distance to the village from the power-house and the desirability of having a form of energy suitable for motor work. The alternators are of the inductor type. Details are given of the switchboard. The primary leads of copper, 0·196 inch and 0·137 inch in diameter, are carried to the centre of the village and then the current is transformed down. There are at present about 2,100 16-candle-power lamps connected. The capital was £9,000, and after all expenses are paid it is expected that the cost for current will not exceed 13*s.* per 16-candle-power lamp per annum.

E. R. D.

Hydro-Electric Installation at Mont-Dore. A. Lavezzari.

(Mémoires de la Société des Ingénieurs Civils, October, 1898, p. 72.)

This installation derives its power from the Lake of Guéry, which is situated about 6·2 miles from the town. A masonry dam built across the end of the lake raises the level of the water 16¼ feet, the superficial area of which is 65 acres. A steel pipe 23½ inches in diameter, 0·16 inch thick, and 940 yards long, gives a head of 130 feet, equivalent to about 250 HP. The

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conduit runs along the left bank of the Dordogne, which it crosses by means of an aqueduct of 48 feet span, placed 13 feet below the surface of the water, and sustained by an overhead timber framing.

At the works a triple junction leads the water to three turbines, which are coupled direct to three dynamos. These furnish continuous current at 550 volts, which is carried to Mont-Dore by a double line of feeders carried over the heights of the plateau of Rigolet. At Mont-Dore the current is reduced to 115 volts, at which tension it is distributed.

The Author gives full details of each part of the installation, including the works of erection, building of the aqueduct, construction of the hydro-pneumatic turbines and dynamos, and means taken for preventing the entrance of foreign bodies into the pipes; and in conclusion, the costs of the various parts of the works, the total of which was £6,250. The erection was completed in 120 days.

The Paper is illustrated by fourteen detail drawings.

H. I. J.

Electric Lifts for the New Brighton Eiffel Tower.

(The Engineer, 6 January, 1899, p. 3.)

The tower has a central spire which rises 500 feet above the ground-level. The lifts are on the system of Messrs. Easton, Anderson and Goolden, Limited. Two passenger lifts and one for goods convey loads to a platform at the 80-foot level. From this level to a platform at the 384-foot level two passenger lifts, each intended to carry 3,000 lbs., are to be used. The cages have a strong framing supplied with a powerful safety-gear, arranged to come into action on any of the suspending ropes unduly slacking. To each lift there are two pairs of flexible ropes connected to the cage at two opposite corners, which are carried up from the cage over a system of guide pulleys placed on girders at the 400-foot level, and from these pass down a suitable trunk formed in the structure of the tower and round a system of pulleys below the 80-foot level, and thence to the winding gear placed to one side. The ropes pass vertically up to the eight-grooved winding-pulley, over four grooves of which they pass, and are then carried down and over four grooves of the cross-over pulley placed below on the skew, and up again over the second set of grooves on the winding-pulley—thus giving the necessary grip—and from thence to the balanced weight sheaves working below, the motion of the latter being reduced to a quarter the lift. The winding-pulley is driven by worm-gearing worked by an electric motor. The motor shaft also carries a brake-drum, acted upon by a magnetic brake, which is automatically applied except when the motor is lifting or lowering.

A. W. B.

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The Electrical Transmission of Power in the Saint-Étienne District. ÉDOUARD SIMON.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, December, 1898, p. 1617.)

An account is given of the use of power transmitted electrically throughout the district of Saint-Étienne, where very important improvements in the local industry of ribbon-weaving have been effected by this means, without hindrance or opposition on the part of the workpeople, and to the great benefit of all concerned. It is estimated that about 30,000 looms are in use, 15,000 in Saint-Étienne itself, and the remainder in a radius of 25 miles round it. Until quite recently nearly all these looms were driven by hand in the houses of the weavers, who worked for themselves at the ribbon trade, and sometimes employed the members of their own families or a few skilled assistants. Ribbon weaving is essentially a home-industry. The Electrical Company of the Loire, founded in 1891, has had the chief share in turning many of these hand-looms into power-looms, driven by electricity. By reference to a map, the operations of this company are explained; the original works were situated at Saint-Victor-sur-Loire, 9 miles from Saint-Étienne, and comprised three turbines each of 300 HP., and two 300-HP. engines in case of failure in the hydraulic-plant. The company, which shortly after its formation united with a smaller one formed with a similar object, now serves 24 communes; the alternating three-phase current is conveyed by 68 miles of wire. Thirty transformer stations are employed to reduce the voltage of the main (5,200 volts) to a pressure of 190 volts for motive power, and 110 volts for lighting purposes. The total power employed by the company at its various generating-stations amounts to 2,200 HP. An account is given of the precautions taken to guard against accidents. There are 8,000 lamps now in use, and 2,500 looms are converted to power-looms. It is estimated that each ribbon-loom needs on the average $\frac{1}{4}$ HP., for which the moderate charge of 8*s.* per month has been fixed to cover all costs. Many different types of electro-motors are in use. All the regulations laid down by the company are given in detail, and the Author points out that many localities where small industries of a similar kind are in operation might study this experiment with advantage.

G. R. R.

On a Transformer by Klingelfuss of Basel. HENRI VEILLON.

(Archives des Sciences Physiques et Naturelles, vol. vi., 1898, p. 313.)

This transformer, intended primarily for use in Röntgen photography, differs in many respects from the ordinary Ruhmkorff coil. The core, which is made of strips of thin sheet iron with

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paper insulation, is bent so as to form three sides of a square, the magnetic circuit being completed on the fourth side by an armature, which may or may not be furnished with an air gap in the middle. There are two primary coils, one on each vertical branch of the core, and two secondaries. The coils are wound by a special machine with mathematical regularity. The primary has 112 turns, and the secondary only 18,000 turns, the diameter of the wire being 0·2 millimetre, but the length of the spark is 42 centimetres, or even 45 centimetres. The Author gives details of a series of experiments with the new transformer and a large Ruhmkorff coil of the ordinary type, giving sparks of the same length, but with 322 turns on the primary and 153,000 turns on the secondary. The results are entirely in favour of the new form. With a current of 10 amperes the discharge of the new transformer was 3,440 microcoulombs as against 524 microcoulombs given by the Ruhmkorff coil, and with 25 amperes the discharge was 6,300 microcoulombs in place of 1,270 microcoulombs; in addition the spark was much thicker. This result is due partly to the form of the magnetic circuit removal of the armature reducing the quantity of the discharge to about one-half, or one-third, with small currents; but it is partly the result of the lower resistance (8,000 ohms) of the secondary coil, as compared with that of the Ruhmkorff, namely, 50,000 ohms.

G. J. B.

A New Submarine Telephone Cable with Fibrous Insulation.

(Archiv für Post und Telegraphie, 1898, p. 716.)

Telephone communication has now become so common overland that it has been felt desirable to connect outlying islands to the mainland by telephone. The first German island to be so dealt with was Sylt, owing to its commercial importance. The postal authorities ordered the telephone cable to be laid in the winter 1896–7. The shortest distance to the island is 6·8 miles, and no submarine telephone line of such length had previously been laid in Germany. It was proposed to use fibrous insulation with a thin lead covering, but it was not known how this would serve in the shoals of the North Sea, but several ship-builders reported that lead of 0·078 inch thickness would last several years in sea water. The cable was therefore made in the following manner. It consists of four copper wires each 0·059 inch diameter, and one of them is tinned. Each wire is insulated with a wrapping of paper 0·17 inch thick. The wires are then stranded and wrapped with impregnated cotton ribbon, the whole then received two lead coverings each 0·394 inch thick, over which is laid asphalted paper and a layer of compound, and a final armouring of fourteen galvanised wires each 0·21 inch diameter, and they are covered

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with two layers of compound. The weight is 8 lbs. per yard. The tinned wire is covered with coloured paper so as to be recognised easily. The lead casing is without joint from end to end, and each of the armouring wires consists of one single length. The maximum resistance of each wire was 17 ohms per mile at 59° F., and the minimum insulation resistance was 310 megohms, and the capacity 0·242 microfarad per mile. The cable was ordered in one piece 13,600 yards long, and weighed about 50 tons, so could not go by rail; it was made by Messrs. Felten and Guilleaume of Mulheim and placed in a barge drawing only about 3 feet of water. By means of this cable a very satisfactory service between Kiel and Westerland is kept up, and a similar cable 5 miles long has since been laid to the island of Norderney.

E. R. D.

The Purification of Acetylene. Dr. Stern.

(Journal für Gasbeleuchtung, 1898, p. 749.)

Notwithstanding the rapid development of the acetylene industry, the question of purification, on which its prosperity depends, does not appear to have received sufficient attention. The impurities in acetylene obtained from carbide of calcium are principally ammonia, sulphuretted hydrogen, and compounds of phosphorus, and it is only the latter that present any considerable difficulties in the practical use of acetylene. The inconvenience and danger attending the use of imperfectly purified acetylene gas are well known; it has an exceedingly disagreeable odour, attacks the gas fittings, &c., and develops, in burning, a bluish-green vapour, containing phosphoric acid. It will probably never be possible to obtain chalk or carbon free from phosphorus, in such enormous quantities as will be required for carbide manufacture, and it may be assumed that phosphuretted hydrogen will always be present. Several processes have been proposed for the practical purification of the gas—Pictet treated it with chloride of calcium and sulphuric acid at a temperature of 14° F., and lower. The inapplicability, on a working scale, of such low temperatures is so evident that it need not be further considered. C. Willgerodt proposed bromine, and Berger and Reychler chloride of mercury; the first is too expensive and also acts upon the acetylene, while the latter is too poisonous to be in the hands of the public, and the employment of mercurial or similar metallic salts has other practical objections. Lunge and Céderkreutz used chloride of lime as a purifying material. This succeeded fairly well in the laboratory; but, on a practical scale, it has not given satisfactory results—it is an unstable body, which undergoes decomposition under certain conditions, and sometimes fires; it also acts upon the acetylene, forming chlorine products which are difficult to remove.

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The chloride also requires frequent renewal and the spent material is almost worthless. Albert Frank, of Charlottenberg, also patented a method of purification by metallic salts, the best being a concentrated solution of hydrochloric acid and copper chloride, with which satisfactory laboratory results can be obtained, and all the impurities are removed at one operation; but its practical application is doubtful, as it partly decomposes the acetylene, and it is probable that the ammonia and particles of lime from the generator would neutralize the solution in the purifier and produce an explosive compound of acetylene and copper. All the foregoing processes have been known for some time, and the fact that none of them have been practically applied speaks best against their utility.

About six months ago Dr. Ullman, of Geneva, introduced a method for purifying acetylene, which appears to satisfy all requirements. The process has been patented and is being worked by the "Hera International Company for Acetylene Lighting." It consists in the employment of a solution of chromic acid with certain other substances, and it completely removes all the impurities at one operation. The solution can be used for a considerable time and can be revivified when saturated. It is used in the "Hera" apparatus, which is a kind of scrubber; and the Ullman method may be regarded as a practical solution of the question of the purification of acetylene.

C. G.

On Refraction. KARL KOSS.

(Mittheilungen aus dem Gebiete des Seewesens, 1898, p. 1001.)

Observations made during the last expedition of the "Pola" show that the dip of the horizon varies, and that the variation depends upon the difference of temperature of the air at eye-level and that of the water on the surface; also that the temperature of the air 0·6 metre (2 feet) above water-level is practically the same as at eye-level (say 48 feet above water-level), and consequently the whole temperature change takes place in the air layer immediately above water-level, and a beam of light from the surface of the water suffers the greatest refraction in this layer. By means of an example the Author shows that under not uncommon atmospheric conditions the error due to refraction in measuring the distance of an object from an observer about 3,000 metres (1·86 mile) away may reach 100 metres (328 feet).

W. B.

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Tensile Strength. W. VOIGT and L. JANUSZKIEWICZ.

(Göttingen Nachrichten, vol. i., 1898, pp. 107–112.)

Assisted by L. Januszkiewicz, the Author shows that the tensile strength of a substance depends on the difference between the longitudinal and transverse tensile stress. This is proved by some experiments on a mixture consisting of 61·5 per cent. of stearic acid, 22·0 per cent. of palmitic acid, and 16·5 per cent. of German paraffin (melting-point 74° to 80°). Rods of the mixture are broken under tension in the air, the pressure at right angles to the pull due to the atmosphere being 10 grams per square millimetre; the applied tensile stress per unit square millimetre equals 145 ± 1·9. Rods are also broken in a vessel containing air at a pressure of 413 grams per square millimetre; the applied tensile stress per unit area equals 146 ± 2·5. The applied stresses are thus practically the same in each case.

The results may be expressed in another form. Let P equal the longitudinal, and D the transverse pressure, in grams per square millimetre. Then

In air	$P = -135$,	$D = +10$
In the vessel	$P = +267$,	$D = +413$

It will be observed that the mixture breaks with a tensile fracture when subjected to a longitudinal pressure.

Besides the above there is a reference to some experiments of a kindred nature on rock-salt.

Tidal Wave in Rivers. PARTIOT.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvi., 1898, pp. 1613–1615.)

The Author explains a method of plotting tidal graphs for different stations on a river by means of observations taken at one of the stations, A suppose. It is necessary to assume some law of velocity of propagation for elementary waves supposed to start from A. The Author tried five different formulas, and compared the results with actual observations made on the Gironde and the Garonne. Boussinesq's formula—

$$\omega = \sqrt{g\,\mathrm{H}}\left(\frac{1+3k'}{4\,\mathrm{H}}\right),$$

appeared to be the best of the five.

G. B. M.

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Specific Heat of Metals at Low Temperatures.

C. C. TROWBRIDGE.

(Science, vol. viii., 1898, pp. 6–11.)

For Cu, Fe, Al, which gave 0·0940, 0·1162, 0·2173 for the mean specific heats between 23° and 100° C., were found 0·0868, 0·0914, 0·1833 for the mean specific heats between the boiling-point of oxygen (− 181·4° C.) and normal temperatures (11° to 15° C.).

R. E. B.

Flame Gases and Electric Discharges. K. WESENDONCK.

(Annalen der Physik und Chemie, vol. lxv., 1898, pp. 553–566.)

To investigate the cause of the comparative immunity of factory chimneys from lightning discharges, the Author reproduces the conditions as far as possible by mounting a horizontal copper tube on a stand, and attaching to one end of it a miniature lightning-conductor, the other end being bent down and serving as an inlet for the products of combustion of a Bunsen burner or other flame. Opposite the lightning-conductor is mounted a metallic disk charged by an influence-machine, and representing an electrified cloud. To prevent discharge from the "chimney," the near end was surrounded by a separate cylinder with a rounded edge. When the machine is working steadily, and the distances are properly chosen, there is a steady glow-discharge between the positive rod and the negative disk, and an electrometer connected with the disk has a constant deflection. On putting a flame under the chimney, the glow is replaced by a brush- or spark-discharge. It is remarkable how sensitive the glow is even to small quantities of products of combustion. When the air of the room contains a certain proportion of them, the glow does not reappear until the air is renewed. When the machine is worked slowly and a brush-discharge is just about to pass into a glow-discharge, flame-gases stop the discharge until the potential rises and a brush-discharge breaks forth again. Sparks are also called forth by products of combustion which have been kept for some time in a copper box, by air containing steam, by simple streams of gas. The Author ascribes the immunity of chimneys and the effects observed to the presence of streams of gases of certain substances, or of special temperatures and velocities.

E. E. F.

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Resistivity of Steels. H. Le Chatelier.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvi., 1898, pp. 1709–1711.)

The specimens of steel experimented on were in the form of bars 20 centimetres long and 1 centimetre square; they were annealed several hours at 600° C. In the following Table the numbers express the specific resistances in microhms per centimetre cube:—

Influence of Carbon.

Resistance.	Composition.		
	C.	Mn.	Si.
10·0	0·06	0·13	0·05
12·5	0·20	0·15	0·08
14·0	0·49	0·24	0·05
16·0	0·84	0·24	0·13
18·0	1·21	0·21	0·11
18·4	1·40	0·14	0·09
19·0	1·61	0·13	0·08

The resistance clearly increases with the amount of carbon, its increase is on an average 7 microhms for 1 per cent. of carbon by weight, or 1·5 microhm for 1 atom of carbon per 100 atoms of iron and carbon.

Influence of Silicon.—An increase of 14 microhms for 1 per cent. of silicon by weight, or 7 microhms for 1 atom of silicon per 100 atoms of alloy. The Author is led to the conclusion that in steel the silicon is not isolated in the form of a definite silicide $FeSi_2$, but is found in the form of a homogeneous mixture, solid solution, or isomorphous mixture, as is the carbon of temper.

Influence of Manganese.—Manganese considerably augments the resistance of steel. This metal, isomorphous with iron, forms with it homogeneous mixtures in all proportions. These mixtures can, however, exist in two allotropic states, unequally magnetic and also possessing resistances notably different. The experiments show an increase of resistance about 5 microhms for 1 per cent. of manganese by weight or in atoms for the non-magnetic alloy. For the magnetic (obtained by annealing 2 hours at 550°) this increase of resistance is only 3·5 microhms.

The Paper also deals with the influence of nickel, chromium, tungsten, and molybdenum. E. C. R.

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Effect of Tempering on Resistivity of Steel. H. LE CHATELIER.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvi., 1899, pp. 1782–1785.)

Tables are given showing the increase of resistance after tempering at various temperatures, ranging from 710° to 1,100°; the samples tested were two ordinary steels, four tungsten steels, and three chrome steels. At high temperatures chromium adds to the increase of resistance due to the carbon alone; tungsten, on the other hand, diminishes it. In all cases the resistance increases with the increase of the temperature up to a limiting value depending on the constitution of the steel.

G. B. M.

Electrolytic Refining of Tin and Treatment of Tin Ores.

S. COWPER-COLES.

(Electrical Engineer, vol. xxii., 1898, pp. 81–82.)

This article gives a description of various processes that have been tried from time to time for the electrolytic refining of tin, and also for the recovery of tin from its ores. The process of Claus, which consists in using an electrolyte of stannate of sodium or sulpho-stannate of sodium, is given as one of the most successful methods for the electrolytic refining of crude tin. Dr. Burghardt's, Classen's, Vortman and Spitzer's, and other electrolytic processes which have been experimented with for the recovery of tin from its ores, are also briefly described.

AUTHOR.

Ashcroft Process for Treatment of Broken Hill Sulphide Ores.

E. A. ASHCROFT.

(Electrician, vol. xli., 1898, pp. 554–558.)

An abstract of the Paper read by the Author before the Institute of Mining and Metallurgy in June. The Paper deals with the trial runs of the Ashcroft process at Cockle Creek, N.S.W., in 1897 and 1898, and with the causes that had led to the failure of the process.[1] A very large number of figures were given bearing upon the costs of the thirteen separate operations incidental to the carrying out of the process. The three chief causes of failure were:—

1. Falling off in the metal contents of the ore sent to the electrolytic works for treatment by the Ashcroft process.

[1] Science Abstracts 1898, No. 687.

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2. Liability to make the process truly cyclic, owing to the accumulation of manganese and other impurities in the electrolyte.

3. Lack of the funds necessary for carrying out the process upon the scale for which the plant had been designed.

The Author believes that the second of these might be obviated by the adoption of a new method of treatment which he has worked out and patented, and that a profit could be earned even with the poorer ores, by working the electrolytic process in conjunction with this "oxide process" at Cockle Creek. The latter process consists in separating the zinc in the form of basic zinc sulphate from the impure electrolyte, and in roasting this to obtain zinc oxide, which is then retorted in the usual manner, in order to obtain the metal. Whereas the first 100 tons of zinc recovered at Cockle Creek cost £75 per ton, and the second 100 tons £28 per ton, the Author states that with a plant designed for working the conjoint process upon the scale of 1,000 tons of ore per week, he could obtain a profit of 20*s.* 3*d.* per ton of ore treated, equal to £50,000 per annum profit upon a capital outlay of £250,000.

J. B. C. K.

Electrolytic Extraction of Metals. D. Tommasi.

(Electrician, vol. xli., 1898, pp. 591–594.)

An illustrated description of the Tommasi electrolyser. This consists of a rectangular tank, containing a circular kathode disk, revolving between two fixed anodes. The disk is only half immersed in the electrolyte; and its upper part passes between two scrapers, which serve to depolarise its surface, and also to remove the deposits of metal when spongy. When the metal is deposited in coherent form upon the kathode, a disk with removable segments is used, and the kathode is stripped by immersing any segment with its deposit, in a bath of the molten metal. The anodes may be in the form of metal plates, or coarse powder packed in perforated receptacles may be used as anode material. A detailed account of the application of this electrolyser to the desilverisation of argentiferous lead is then given. The electrolyte used consists of a mixture of lead acetate with acetate of sodium or potassium, and of some undivulged compounds in addition. Cast anodes of the argentiferous lead are used. The revolving disk may be of aluminium bronze, nickelled iron, copper or sheet iron. It should be 3 metres in diameter, and make 1 to 2 revolutions per minute. The deposit will be spongy in character, and may be removed by the scrapers at intervals. The detached lead sponge is washed, pressed, and melted with 2 to 3 per cent. of carbon in order to obtain it in ingot form. The silver remains behind as a sludge on the bottom of the electrolyser. Theoretically no appreciable electromotive force should be required to transfer the lead

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from the anode to the kathode. Practically 0·75 volt is requisite. Calculations are given by the Author which show that with a plant producing 25,000 to 30,000 tons of lead per year of 300 working days, the cost per ton with steam-power would not exceed 8·60 francs, and with water-power would not exceed 5·80 francs. Adding all incidental charges, the cost per ton should not exceed 10 francs, whereas the cost of the usual refining process is stated by the Author to be 30 francs per ton. The spongy lead, instead of being melted down into ingots, may be used directly for (1) accumulator plates; (2) the manufacture of massicot, litharge, or minium; (3) the manufacture of lead carbonate. According to the Author all these products can be produced much more cheaply from the electrolytic lead sponge obtained in his process than by the present processes of manufacture.

J. B. C. K.

Lightning and Lightning Arresters. H. E. Raymond.

(Electrical World, vol. xxxi., 1898, pp. 713–715 and pp. 772–775.)

In these articles the Author differs from Mr. Wurts, and thinks that frequently arresters of the short-gap type having a resistance in series are of more value than the non-arcking metal type. An arrester ought to act at a voltage not much greater than the working-line voltage. The gap ought to be as short as possible, but such that the current cannot follow a discharge. No swinging, fuse blowing, or mechanical devices should be used to effect this. In installing, one arrester at least should be placed so as to receive the crest of any wave liable to reach the generators, and another set placed so as to obtain the benefit derived from the natural impedance of any length of wire. A lightning arrester affords but little protection from a direct "stroke."

W. G. R.

Lightning Arresters. A. J. Wurts.

(Electrical World, vol. xxxii., 1898, pp. 5–6.)

There are two types of lightning arresters dealt with here, one using a spark-gap and a resistance in series with it, the other several spark-gaps without any resistance in series. The Author is of opinion that spark-gaps without resistance in series should be used on account of the suddenness of a lightning discharge. The Fire Underwriters' rules require that lightning arresters must be connected with a thoroughly good and permanent ground connection by metallic strips of wires having a conductivity not less

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than that of the No. 6 B. and S. wire, which must be run as nearly in a straight line as possible from the arrester to the earth-connection. Why then put a resistance in the arrester?

W. G. R.

Lightning and Lightning Arresters. H. E. RAYMOND.

(Electrical World, vol. xxxii., 1898, p. 73.)

The Author advocates the use of an overhead barbed wire for protection against direct lightning flashes from cloud to earth, since an enormous installation of station and line arresters would be required to adequately protect any system from the effects of a very heavy "main path" discharge in close proximity to the line. Arresters form sufficient protection against inductive discharges, but not against "main path" discharges.

W. G. R.

Metallic Resistances. E. K. SCOTT.

(Electrical Review, vol. xliii., 1898, pp. 71–72, 107–108, and 187–188.)

Six tables are given, in which are tabulated the resistance, size of mandril, length of wire in a given spiral, weight, price, &c., of German silver, platinoid, galvanized iron, manganin, Kruppin, Hadfield's "Resista," and Brunton's "Beacon" material. The sixth table gives particulars of resistance, weight, and price of expanded metal (iron). In practice it is stated as usual to wind the wire as a close coil spiral, and then pull it out to double the length, but the smaller sizes below No. 15 B.W.G. require drawing out rather more to give the necessary stiffness. The "Beacon" alloy, made by Messrs. Brunton & Son of the Musselburgh Iron Works, Scotland, is given as having resistance about forty-eight times that of copper, and a temperature-coefficient of 0·007007.

Extra large resistance-frames, for use in testing, &c., may be cheaply made of ordinary galvanized iron-wire netting folded up and down on a large wooden frame. Or a strip of netting, say 12 inches wide and 1-inch mesh, may be wound round and round from the centre outwards, adjacent layers being spaced about 3 inches apart by means of $\frac{3}{4}$-inch diameter iron rods at the four corners of each convolution. The resistance of iron-wire netting, No. 20 B.W.G. 1-inch mesh and 12 inches wide, is given as 0·005 ohm per yard of length, and the safe-current, with good ventilation, may be as high as 90 amperes to 100 amperes. Three designs for resistance-frames are illustrated, and also a diagram showing the distance apart of supports for wire spirals of various diameters. It is stated to be mistaken policy to skimp the ironwork

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of resistance-frames, as the extra metal gives mechanical stiffness and materially assists the cooling. In America grids made of cast iron have been used as resistances with success. The Siemens iron tube resistances, the "packed card" and tramcar rheostats of the General Electric Company (U.S.A.), and the Carpenter and Stewart Electrical Syndicates enamel resistances are described. With regard to these enamel rheostats, it is stated that, without reckoning in the area of the radiating ribs, the Carpenter types will dissipate continuously 5 watts per square inch of overall plate area; thus the size 10 inches square will dissipate 500 watts.

AUTHOR.

Gas Power. J. E. DOWSON.

(Mechanical Engineer, vol. i., 1898, pp. 703–704.)

Practically the gas-engine trade began with the four-stroke cycle engine patented by Otto in May, 1876. From 1877 up to the end of 1897, the British and German makers sold 61,370 Otto engines, giving a total of 508,025 brake HP. The early engines had a compression of about 35 lbs., whereas the larger ones now compress to 100 lbs. per square inch before ignition; and the consumption of gas has been reduced from 32 cubic feet per brake HP. hour to about half that quantity. Engines are now built to indicate 220 HP. each, and in one installation at Blackpool the gas-engines work regularly to 940 I.HP.

When town gas costs 3*s.* per 1,000 cubic feet, the working cost of a gas-engine indicating 20 HP. exceeds that of a steam-engine of the same power. Hence in 1878 the writer introduced a plant for producing cheap fuel-gas, tried in a Crossley engine in 1879. Results are given of trials made of the gas-power electric-light station at Leyton in 1896 and 1897. Four "Premier" gas-engines, of Wells Brothers, each giving 55 brake HP., are driven by Dowson gas. Total fuel consumed, anthracite and coke, 0·9 lb. per indicated and 1 lb. per brake HP. hour, and 2 lbs. per Board of Trade unit sold. Total cost of fuel, labour, &c., per unit generated is 1½*d.*

At Leicester four Crossley engines, each of 50 brake HP., and two of 25 brake HP., work with Dowson gas, and the total fuel consumed was reduced from 4·6 lbs. in 1895 to 3·03 lbs. per Board of Trade unit generated in 1897. At Halifax two engines of 60 brake HP. each drive dynamos, and use 1·01 lb. of anthracite per I.HP. hour, and 1·92 lb. per electric unit generated. Other instances go to show that the consumption of fuel in gas-engines with Dowson gas is much less than in the best type of steam-engine. Anthracite peas can be used, costing 6*s.* to 7*s.* a ton at the pit, and nuts and cobbles cost 5*s.* to 6*s.* a ton more, yet with care the peas can give rather better gas. Good clean coke also makes Dowson gas.

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Ludwig Mond has a large plant producing fuel-gas from bituminous coal or slack, chiefly for the recovery of ammonium sulphate. Some of the gas is used for heating furnaces, and the rest for driving gas-engines. Each producer makes gas enough for 2,000 I.HP., per hour, and must work continuously day and night. The plant is too large and costly for power purposes on a moderate scale.

The writer compares the repairs and maintenance of a gas-plant with that of a steam-boiler of the same power. In a Dowson gas-plant the firebars, hopper valve, and some of the brick lining of the generator, also coke in the scrubbers, have to be renewed occasionally, not oftener than once a year, besides painting of iron-work. The cost of repairs for plant varies with the size; between 100 I.HP. and 500 I.HP. plant is about £4 per annum to £14 per annum.

W. R.

Bending Heavy Rails.

(Western Electrician, vol. xxiii., 1898, pp. 29, 30.)

This is a description of a bending machine designed by C. E. Moore to bend 7-inch 90-lb. rails. The machine takes 12 HP. to operate it, and curves a 90-lb. rail at the rate of 40 feet per minute. Formerly it required nine men 4 hours to bend one 90-lb. rail. The cost of bending has been reduced from 13 cents to 1 cent per foot.

A. S.

New Plant at Niagara Falls. O. E. Dunlap.

(The Electrical Engineer, New York, vol. xxvi., 1898, pp. 73–75.)

The Niagara Falls Hydraulic Power and Manufacturing Company have just placed in operation the first turbine and generator installed in the extension of their power-house. The addition to the building is 60 feet long by 100 feet wide, bringing the total dimensions of the power-house up to 120 feet by 100 feet. A steel penstock about 11 feet in diameter has been constructed to supply water for the new turbines; it extends horizontally out from the cliff for about 60 feet, and then vertically for about 200 feet, finally passing under the floor of the power-house. The first of the five new turbines to be installed is of the Jonval-Geyelin improved type, consisting of two bronze wheels on a horizontal shaft contained in a heavy cast-iron casing: the total weight of the turbine is 21 tons, and it develops 2,500 HP. This wheel is to operate two alternate-current generators, one of which already supplies current to the National Electrolytic Company.

Aluminium has been used for the conductors from this generator

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to the works; from the power-house to the top of the bank these conductors are bracketed to the penstock, and consist of bars 25 feet long and 6 inches by ½ inch in cross-section, four being placed in parallel riveted together; at the top of the bank each group of bars is connected to twelve aluminium cables rubber-insulated. The core of each cable is about 1¼ inches in diameter, composed of No. 10 wire. The total amount of aluminium in the conductors is about 22,000 lbs., the same work in copper would require about 48,000 lbs. The conductivity of the aluminium used as compared with copper of the same section is about 63 per cent., but for the same weight it is more than double. Aluminium cables, although requiring more insulation, present many advantages, as the great strength and lightness of the material enable long spans to be used, reducing the number of poles and insulators required, while large cables can be handled and erected with ease and rapidity.

The Paper contains a detailed description of the new turbines, alternators, switchboards, &c., and two views of the new penstock.

M. G. W.

Power-Station at Toledo, Ohio. W. S. Smith.

(Electrical World, vol. xxxi., 1898, pp. 491–493.)

The Author gives an account of the power-station recently erected by the Toledo Traction Company to meet the increased demands upon the power, traction, and lighting system controlled by this company. The chief point of interest is the arrangement of the generators. There is one Lake Erie engine of 1,200 HP. driving by belt one 6,000-light Westinghouse alternator, and one 5,000-light G.E. alternator. Two 800 HP. Porter-Allen tandem engines each carry on the shaft two 200-kilowatt G.E. lighting generators for the three-wire system. Four 1,200 HP. Wheelock cross-compound engines each drive by means of ropes one section of a shaft 198 feet long. These four sections may be all connected by means of friction clutches. At each end of the shaft are connected two 100-kilowatt G.E. generators for the three-wire system, and between these are a number of rope-driven machines; the latter include seventeen arc-lighters, four alternators, one booster, and three generators for the power service. Besides driving this shaft, each Wheelock engine carries upon its shaft a 500-kilowatt G.E generator, three of these being used for traction, and the fourth as a reserve for traction and power service. Owing to the combined traction and lighting supply, a comparatively constant load results, and the arrangement of plant described enables the machinery to be run at a higher load than would be otherwise possible. The Lake Erie engine supplies the alternating incandescent load, and the Porter-Allen engines the direct-current

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load during heavy demand. As the lighting load diminishes, it is taken by the auxiliary dynamos on the shaft, so that for the greater part of the day the whole load is taken by the traction plant.

W. R. C.

Accumulator Tramway Traction. E. Hauswald.

(L'Éclairage Électrique, vol. xv., 1898, pp. 536–543.)

Abstract of a Paper read before the Elektrotechnischer Verein, 25 January, 1898.

The Author, after making some general statements as to the desirable characteristics of a traction cell, refers to the Pollak cell, and states two experimental laws:—(1) A plate will only bear a high rate of discharge if the discharge amounts to a fraction of its normal capacity. (2) The higher the efficiency at which a plate is worked the longer is its life. Curves are given showing the variation of efficiency with rate of discharge and with the amount of discharge. The Author calculates the power required to propel a car. The mean results obtained on the accumulator line at Frankfort show that the energy required per car-kilometre for an 8-ton car travelling at 15 kilometres per hour is as follows:—

	Watt-hours.
Without stops	180
With three stops, battery coupled in series at starting	320
" " " " parallel at starting	260

It therefore appears that accumulator-cars can be run at 30 watt-hours to 40 watt-hours per ton-kilometre, instead of 60 watt-hours, which is the generally accepted figure. Having regard to the above laws, the battery employed should be small, discharged to only a small extent and frequently recharged. This system is employed at Frankfort. The cars carry forty-two passengers, but only weigh 8 tons, including a battery of 84 T_6 Pollak cells. A single motor of 15 HP. is provided. The batteries are charged at the rate of 2 minutes per kilometre run, at constant pressure so that gassing does not take place; once a week they are charged up to 2·5 volts per cell. The battery efficiency amounts to 85 per cent. Such a system is only suitable for short lines. When the distance exceeds the efficient limit, mixed traction may advantageously be employed, the trolley line being sufficiently long to give the requisite charge.

The Author also considers accumulator-traction for suburban railways.

Hopfelt remarked that the first above-mentioned law applies to Faure, but not to Planté plates.

W. R. C.

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Cost of Electric Traction at Leeds.

(Railway World, vol. vii., 1898, pp. 142–143.)

The cost of tramway traction at Leeds is discussed. The following figures were obtained for the week ending March 28 last, and may be considered as a fair average:—

Total receipts from twenty-one electric cars	£656 16*s.* 4*d.*
Total car-mileage	14,777
Receipts per car-mile	10·66*d.*
Expenses per car-mile (including depreciation, renewals, repairs, interest and sinking-fund)	8·60*d.*
Surplus per car-mile	2·06*d.*

The working expenses per car-mile, with no allowance for depreciation or repairs, is made up as follows:—

	d.
Electric-car shed	0·57
Generating station	0·69
Management and office	0·32
Electrical engineers' salaries	0·13
Wages of drivers and conductors	1·84
	3·55

The energy used per car-mile amounted to 0·960 unit, and the cost of generation was 0·72*d.* per unit. The interest charged appears to be at the rate of 2¾ per cent. on the Corporation Loan; the sinking-fund is at 2¼ per cent. Depreciation, renewals, and repairs are all included in a sum of 7½ per cent. on the capital.

W. R. C.

High-Speed Traction Motor for Suburban Service.

(Street Railway Review, vol. viii., 1898, pp. 465–466; The Electrical Engineer, New York, vol. xxv., 1898, pp. 720–721.)

The new type of General Electric Company's high-speed motor, known as G.E. 51-B, is illustrated and described. The capacity of these motors is 80 HP., based on a rating of 75° C. rise in temperature of the windings above that of the surrounding atmosphere after an hour's run at rated load. A double equipment of these motors will propel a 20-ton car at a maximum speed of 26 miles per hour on a level, with the gear ratio of 2·27. Mounted on 33-inch wheels, the clearance between the bottom of the frame is 3 inches.

E. H. C.-H.

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Dick's System of Train-Lighting.

(Zeitschrift Elektrotechn Wien, vol. xvi., 1898, pp. 321–327.)

A detailed description, with a sketch of the electrical connection of Dick's system of train-lighting. Each carriage is provided with a battery of fifty-seven small secondary cells, capable of giving a current of 3 amperes for over 8 hours. The batteries are joined in parallel across main conductors running the entire length of the train, connection between neighbouring carriages being established by means of flexible conductors. A single 12-HP. dynamo, mounted after the manner of a tramway motor, so as to be driven off the carriage axle by toothed gearing, is used for either charging the cells or supplying the lamps direct, in which case the cells act as regulators. An elaborate array of electro-magnets controls the various automatic switching arrangements, the required constancy of electromotive force with variable train speed being obtained by throwing more or less resistance into the field circuit. The only hand control is that of a simple two-way switch attached to each carriage, in one position of which the lamps are on and in the other off.

A. H.

Richter's Electric Miner's Lamp.

(Electricien, vol. xv., 1898, pp. 275–277.)

This is an accumulator lamp, and the improvements relate more particularly to the box and fittings. The box is provided on opposite sides with terminal sockets of different sizes for charging, the sockets being connected by double plugs; the ends of these plugs are of different diameters, to correspond with the sockets, so that the batteries can be readily coupled up in series for charging without risk of any of the batteries being connected up in the reverse direction. Some drawings are given in the Paper, but the description is not very full. The lamp weighs 3 kilograms, burns 10 hours, and gives 3 candle-power.

C. K. F.

Automatic Telephone Exchanges.

(Electrician, vol. xli., 1898, pp. 52–53.)

Describes the apparatus of "The Direct Telephone Exchange Syndicate, Limited." Two lines are necessary for each subscriber, and in addition either an earth-return or, preferably, a return wire common to all subscribers. The subscriber's instrument is provided with a disk in which are holes numbered 0 to 9. The

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calling subscriber selects the successive figures of the required subscriber's number and operates the disk for each figure. He then turns the handle of his magneto bell. If the connection is made his bell rings; if the required number is already engaged his bell does not ring. The operation of the disk first makes a combination circuit from one or other of the lines with the common return, and secondly sends a number of current impulses over the selected circuit.

In the Central office mechanism an insulated segment of impregnated plaster-of-Paris has placed upon it 100 contacts in ten columns of ten rows, each contact representing one subscriber to the exchange. A "wiper" connected to a movable shaft travels over the segment and is brought into position over the particular contact required by means of the combination lines and the current impulses transmitted over them from the calling subscriber's instrument. Mechanism is provided whereby a connection to an already engaged line is prevented. At the central office each subscriber's line is provided with the selective apparatus, upon which each line is "multiplied" twice, first for connection purposes, and secondly for preventing connection in case of engagement. In exchanges exceeding 400 lines a supplementary automatic switch is necessary for each subscriber.

J. E. K.

Flicker Photometer. O. N. Rood.

(Science, vol. vii., 1898, pp. 757–759.)

A description is given of a photometric method founded on flickers. The two sides of a white upright 90° prism are illuminated with the lights to be compared, and the flicker is brought about by the rapid motion of a cylindrical lens, or biprism of small angle placed opposite the angle of the white prism. The lens is caused to oscillate horizontally by a train of toothed wheels, turned by hand or by a small electro-motor. By this means the two illuminated sides of the prism are presented rapidly in succession to the eye, placed beyond an aperture in front of the lens. Results of considerable accuracy were got even by persons unused to photometric work.

J. J. S.

[Note.—In a subsequent Paper (Science, vol. vii., 1898, pp. 785–786) the Author describes the application of the flicker photometer to obtain a measurement of the relative extents of colour-blindness.]

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Joly Colour-Photography Process. J. S. Gibson.

(Engineering News, vol. xxxix., 1898., pp. 298–299.)

The Joly process is based on the fact that the eye is unable to differentiate colours lying within a certain area, termed by the Author the "Retinal unit," and which does not exceed 2 minutes or 3 minutes of arc. Consequently, if the three primary components of a primary colour are placed side by side within the limits of this retinal unit, the area appears as of the composite colour. The process therefore differs in principle from Ives' in that the synthesis is effected by juxta- instead of super-position. The practical working is as follows: The light, before falling on the photographic plate, passes through a "taking screen." This is a gelatine-coated glass plate, ruled with tricolour bands (orange-red, yellowish-green, and blue), each colour-line being $\frac{1}{175}$ inch broad. The light, passing through this, is split up into its three components, arranged side by side in a space of $\frac{1}{75}$ inch, and the resulting negative consists of bands of silver deposit proportional in density to the intensity of the components of the colours. From this a positive is taken, in which the densities are reversed; on this is placed a "viewing screen," similar to the "taking screen" except that the colours are red, green, and violet. This, if correspondingly superposed, provides the component colours, which are regulated in intensity by the density of the positive plate, and are synthesised by the eye. The breadth of tricolour band required for perfect synthesis is about $\frac{1}{400}$ inch at the ordinary range of vision, but $\frac{1}{75}$ inch is found sufficiently narrow in practice. Exposure must be made through an orthochromatic screen (picric acid stain) on orthochromatic plates to obtain photographic equality in the colours.

G. H. Ba.

Conversion of Kathode Rays into Light. E. Wiedemann.

(Wiedemann's Annalen, vol. lxvi., 1898, pt. i., pp. 61–64.)

The alleged economy of luminescent or fluorescent sources of light is based upon the fact that the maximum energy radiated by them lies in the visible spectrum, the infra-red rays being practically absent. But when the expenditure of energy necessary to produce this glow is considered, the economy is very small. The Author determined the heating effect which accompanies luminescence by inserting a calorimeter vessel in a vacuum tube, leaving it open at the top, and painting its bulb with Balmain's luminous paint or with Sidot's blende. He found that only about 5 per cent. or 7 per cent. of the incident energy was converted into light, that being about the same ratio as in the glow lamp.

E. E. F.

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Röntgen and Kathode Rays. J. von Geitler.

(Wiedemann's Annalen, vol. lxvi., 1898, pt. i., pp. 65–73.)

The Author quotes a number of experiments to show that Röntgen rays are absolutely incapable of conveying a charge. They can equalise opposite charges, by rendering the air between them conducting, but they cannot, like kathode rays, convey an electric charge into the interior of a closed metallic vessel connected to earth, or out of such a vessel into the open air.

E. E. F.

Corpuscular Theory of Röntgen Rays. B. Walter.

(Wiedemann's Annalen, vol. lxvi., 1898, pt. i. pp. 74–82.)

Instead of regarding Röntgen rays as intermittent waves they may be regarded as discharged kathode particles. Then the absence of magnetic deflection would follow as a matter of course. They penetrate the walls of a tube with greater ease than kathode rays on account of the absence of electric charge. They are undoubtedly much smaller than the electro-chemical ions. That their absorption should vary as the density of the absorbent is easily understood. Their power of ionizing gases must be attributed to the destruction caused by their impact upon gaseous molecules.

E. E. F.

Surfusion of Metals and Alloys. Sir W. C. Roberts-Austen.

(Proceedings of the Royal Society, vol. lxiii., 1898, pp. 447–454.)

By means of the photographic recording thermo-element, the phenomenon of surfusion is shown to occur with gold, copper, bismuth, antimony, tin, and lead. Reproductions of several of the curves are given in the Paper. Surfusion is also observed with alloys, but the curves are more complicated, owing to the formation of super-saturated solutions. The alloys of tin and lead are fully studied from this point of view. It is suggested that the extreme instability of metals in a state of surfusion may be due to the introduction of crystalline nuclei from the metallic vapour given off. An appreciable quantity of vapour is evolved by metals even at low temperatures. Silver and cadmium placed at some distance apart in a vacuous tube at 50° yielded a coloured film of silver cadmium alloy on the silver after 8 days.

T. E.

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Mechanical Equivalent of Heat.

O. REYNOLDS and W. H. MOORBY.

(Memoirs of the Manchester Literary and Philosophical Society, vol. xlii. pt. vi., 1897–8, pp. 1–54.)

Water at 0° C. was forced at a steady rate through a vessel wherein it was churned so as to issue at 100° C., an internal stirrer being rotated by steam-power while the vessel was balanced by an external brake-dynamometer which measured the work absorbed. For details the Paper must be referred to. The final result obtained is 776·94 in British gravitation-units at Manchester, which in C.G.S. absolute units gives 41,832,000, the heat-unit being the hundredth part of the heat required to raise 1 lb. and 1 gram respectively of water from 0° C. to 100° C. The method is due to the former of the Authors, the experimental determination to the latter.

R. E. B.

Resistance of the Human Body. J. E. BOYD.

(Physical Review, vol. vii., 1898, pp. 115–118.)

A reading was taken with a Duncan dynamometer in series with a non-inductive resistance of 1,550 ohms, which was then replaced by the body. The fingers were dipped into a solution of ammonium chloride, two large battery carbons forming the electrodes. For alternating currents of from 2 volts to 7 volts, 0·0014 ampere to 0·0044 ampere and 62 periods, the resistance, hand to hand, varied between 1,478 ohms and 1,622 ohms; for continuous currents of about the same strength and tension between 1,598 ohms and 2,078 ohms. In a second series of tests, Ayrton's method was applied, the current being measured by a Weston voltmeter, and the drop of potential with a condenser and galvanometer. Platinum foil strips, fastened to the body, served as condenser terminals. By this method the total resistance, jar to wrist, wrist to wrist, wrist to jar, aggregated 1,334 ohms. The hands above the liquid were not thoroughly dry, hence probably the smaller resistance.

H. B.

Resistance of the Human Body. DUBOIS.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvi., 1898, pp. 1790–1792.)

In these experiments a condenser is connected with a battery for a very short period by means of a steel ball impinging on a mass of steel and rebounding. Various resistances are inserted in the path of the current, and the results compared by means of a

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ballistic galvanometer. The Author concludes *inter alia* that during the state of variable flow the resistance of the human body is much less than its ohmic resistance; that this resistance is unaltered, for the same position of the electrodes, in spite of large variations of the ohmic resistance; and that the body, considered as a condenser, has a capacity of about 0·165 microfarad.

G. B. M.

Measurement of Resistance of Glow-Lamps.

R. Apt and H. W. Hoffmann.

(L'Éclairage Électrique, vol. xiv., 1898, pp. 566–569; and Elektrotechnische Zeitschrift, 1898, p. 122.)

The method usually employed for the above purpose is not strictly correct, the resistance being deduced from ammeter and voltmeter readings; the current taken by the latter, of course, introduces an error. The method suggested by the Authors is a modification of that employed by E. Wiedemann, in which a Wheatstone bridge is used, the lamp being inserted in one of the branches. This method, although more accurate than the preceding one, does not make use of all the advantages of the Wheatstone bridge test. The Authors propose to employ the bridge by causing an auxiliary current to pass through the lamp in addition to the main current. The connections are analogous to those of the Paalzoid and Rubens bolometer method. The above method possesses the disadvantage of being somewhat complicated, and also that if one of the lamp circuits is accidentally broken a strong current will pass through the battery and galvanometer and may injure them.

L. J. S.

Magnetic Properties of Tempered Steel.

Mme. Sklodowska-Curie.

(Bulletin de la Société d'Encouragement, Paris, série v. t. 3, p. 58; also L'Éclairage Électrique, vol. xvi., 1898, pp. 151–155.)

The Authoress gives the I-H curves of five steels from the steel manufactory of Firminy, having increased percentages of carbon, a carbon steel of Unieux, Allevard steel, a tungsten steel, a steel with 3 per cent. nickel, a steel with 0·7 per cent. manganese. An examination of the curves shows that the introduction of different metals slightly modifies the residual intensity of magnetization in a closed magnetic circuit; it augments the coercive field and the hysteresis, and diminishes the maximum intensity of magnetization induced. The curves were obtained with values of H between ± 500.

E. C. R.

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Solubility of the Carvoximes. H. GOLDSCHMIDT and H. C. COOPER.

(Zeitschrift Phys. Chem., vol. xxvi., 1898, pp. 711–718.)

In order to test the suggestion that the right- and left-handed modifications of an optically active substance may be unequally soluble in an active solvent, the Authors have determined the solubilities of *r*- and *l*-carvoximes in *r*-limonene at different temperatures. The two solubility curves are found to be identical. Again, if the racemic compound of the two carvoximes exists in the liquid state the solubility of the fused mixture of *r*- and *l*-carvoximes should be smaller than that of the pure active modifications. Using a mixture of water and alcohol as solvent no difference in these solubilities could be detected. In presence of aqueous alcohol the carvoximes melt at a temperature some 20° below their ordinary melting points, owing to the solubility of water in the fused substances.

T. E.

Dynamo Design. J. K. SUMEC.

(Zeitschrift Elektrotech Wien, vol. xvi., 1898, pp. 454–458 and pp. 469–474.)

The methods hitherto commonly in vogue for determining the dimensions of a dynamo from its output and speed consist in using a formula (such as those proposed by Esson, Snell, Kapp and others), connecting output with speed and length and diameter of armature. Such formulas involve a coefficient depending on the type of machine and (more particularly in the case of alternators) the skill of the designer. The Author makes a departure from this time-honoured practice, and proposes the following plan of designing a dynamo. The output of a machine may be expressed by the formula—

$$W = 10^{-8} \cdot v \gamma B k D \pi l,$$

which does not contain any arbitrary coefficients. In this formula, W = output in watts; v = peripheral speed in centimetre-seconds; γ = total current, in amperes, per centimetre length of armature circumference; B = mean magnetic induction under pole-pieces; k = ratio of width of pole to pitch; D = diameter, and l = length of armature, in centimetres. In accordance with the conditions under which the machine is to be used, a suitable value of v is assumed; from this, and the known revolutions per minute, D is at once determined. The values of γ and B are determined by considerations regarding heating; k will depend on the type of machine. The above formula then gives l, and thus the dimensions of the machine are completely determined. When dealing with alternators, the right-hand member of the formula

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has to be multiplied by half the value of Kapp's coefficient. The Author works out, by the above method, the design of a 22·5-kilowatt dynamo, a 150-kilowatt three-phaser, and a 75-HP. induction motor. The various methods of dealing with armature reaction in dynamos, alternators, and induction motors form the concluding part of a valuable Paper.

A. H.

Drum Armature Windings. A. L. Rice.

(American Electrician, vol. x., 1898, pp. 319–321.)

The Author shows how to wind an armature which was designed for a multiple-circuit winding, so that it shall have a two-circuit winding. He takes as an example a four pole four-circuit armature with forty-eight conductors, in formed coils laid in slots. In order to convert this to a two-circuit winding, two conductors must be left out; so one end of a coil is disconnected from the commutator and insulated, and the commutator bar to which the other end of this coil is connected is short circuited on to the next commutator bar. The Author also shows how to convert a six-pole six-circuit winding to a two-circuit winding. The Paper is illustrated by diagrams.

R. B. R.

Reduction of Inductance of Armature Coils.

(Electrical World, vol. xxxii., 1898, p. 185.)

The improvement in the construction of armature cores consists in punching a set of tangential slots immediately underneath the teeth, so as to form a narrow rim in which the induction is pushed to a very high value. The inductance of the windings is thereby reduced, and sparkless running facilitated. Tests carried out on two armatures of the same size and similarly wound, but having different cores, one of the ordinary and the other of the improved type, showed a reduction in the core losses of the latter which resulted in a 2 per cent. gain in efficiency.

A. H.

Direct- and Alternating-Current Distribution. L. A. Ferguson.

(Electrical World, vol. xxxi., 1898, pp. 779–781, and vol. xxxii., 1898, pp. 7–10.)

The Author in this Paper, read before the National Electric Light Association, June, 1898, describes the distribution system of the Chicago Edison Company, as representing the latest developments. The continuous three-wire network is supplied from

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four central stations whose maximum output in 1897 was 50,730 amperes at 215 volts. The average yearly efficiency of distribution was 91·2 per cent. from the station switchboards to the customer's meter. The largest station is connected to a sub-station in the centre of distribution in the business district by an immense trunk line, 3,340 feet long, having a total cross sectional area of 66,000,000 circular mils, which has carried a maximum of 34,400 amperes. Outlying districts are supplied from the large stations through rotary transformers which take direct current from the bus bars at 215 volts and convert it to three-phase alternating at 160 volts, which is raised by step-up transformers to 4,500 for transmission. At the receiving end, the volts are stepped down to 80 and then converted into direct-current at 115 volts by means of rotary transformers. A pair of 200-kilowatt generators is being installed for this work, each being provided with three collector-rings and designed to deliver from the same armature direct-currents and three-phase alternating currents.

In the second part of his Paper the Author discusses arrangements for obtaining uniformity of pressure. For long feeders he recommends a series-wound booster, connected in series with the feeder and so designed that its voltage at constant speed will be proportional to the current passing through it. The standard system used by the Edison Companies throughout America consists of lengths of japanned iron pipe containing three solid copper wires or rods insulated from each other and from the iron pipe by an asphaltum compound. The tubes are 20 inches long, the conductors projecting 3 inches beyond the ends. Tubes are connected at junction-boxes filled in with hot insulating compound. At each street intersection is fixed a cylindrical junction-box containing three copper rings, to which the conductors are attached. This is the most complete and permanent system for direct-current distribution at 500 volts and under. Pressure charts illustrate the superiority in regulation of a direct over an alternating system. With the former, an average deviation of less than 1 volt should be obtained. To obtain first-class pressure-regulation with alternating distribution, the engineer must follow the lines laid down for the modern direct-current distribution system. As regards batteries, they are economically valuable in direct-current systems whose load curve has an average peak-width of not more than 2 hours, since the investment required for storage batteries to carry a peak of less width, is less than the investment required for steam and electrical machinery to do the same work. The superiority of direct-current for electric elevator work is emphasised and, as proof of the importance of this service, it is stated that the Edison Companies in New York, Boston, Brooklyn, and Chicago, supply for direct-connected elevators, 15,000 HP., representing a gross income of 375,000 dollars annually. The Author finds that the 3½ amperes direct-current enclosed arc lamp successfully competes with the Welsbach gas-burner. In conclusion the opinion is expressed that the successful central

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station company of the future will be the one combining intelligently the use of alternating and direct currents, employing direct current for the distribution systems in the thickly settled business and residential districts, and alternating current for the distribution systems in the suburbs. The energy will be generated at one or two large condensing stations which will transmit low pressure direct-current, or high pressure alternating-current, according as the sub-stations which they supply are relatively close at hand or far away.

E. H. C.-H.

Electrical Transmission of Energy. A. SIEMENS.

(Electrical Review, vol. xliii., 1898, pp. 406–408.)

In this Paper, read before the British Association, the Author discusses the subject of electrical transmission in general, and describes the installation at the works of Siemens Bros. & Co., Charlton. The load factor during 1897 was 0·18; special tests in May and June 1898 showed the day-load factor to be 0·36, with a consumption of 5·13 lbs. of coal per B.T.U., while the night-load factor was 0·10, with 10·42 lbs. of coal per B.T.U. The average coal consumption was 6·55 lbs. per B.T.U. The cost, inclusive of all charges, was 1·287*d.* per B.T.U. at the switchboard, and 2*d.* per B.T.U. given out by the motors. The expenses were divided as follows:—

	Per cent.
Standing charges	49·1
Fuel	2·68
Labour	12·0
Stores	6·0
Repairs	6·1

Particulars are also given of two installations for long-distance transmission on the three-phase system at 10,000 volts pressure.

A. H. A.

Electrical Motive Power in Small Industries. A. H. GIBBINGS.

(Electrical Review, vol. xliii., 1898, pp. 408–410.)

In this Paper, read before the British Association, the Author summarises the uses to which small electromotors may be applied, and discusses the reasons why they are not more generally adopted; he advocates the hiring-out of motors at a rental of about 10 per cent. upon their cost, and gives data showing the results of this system in two years' working at Bradford. A list of direct-current central stations, with the number and HP. of the motors supplied by them, is added.

A. H. A.

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Capacity of Wires. W. Moon.

(Electrical Review, vol. xliii., 1898, pp. 478–480.)

The limits of the capacity of multiple cables can be stated; thus the capacity between a wire X and a number of other wires and the earth cannot be as great as twice the capacity between X and the nearest wire. In the case of wires on poles, the capacity between X and the remaining wires and earth is not as great as that between X and an infinite plane at the distance of the nearest wire. The capacity between one wire and any system of wires and the earth could in no case be as great as twice the capacity between one wire and the earth. In a perfect telephone looped circuit, the effective capacity of one wire may be taken as the sum of the capacity of either wire with the remainder and earth, and the capacity between the two wires and the loop.

M. O'G.

Conductor-resistance of Cables Corrected for Leakage.

W. J. Murphy.

(Electrician, vol. xli., 1898, pp 519–522.)

A simple method of arriving at Schwendler's results. The rules are :—

I. The "fall" in C.R. due to a leak is directly proportional to the square of the conductor resistance beyond the apparent position of the leak, and inversely proportional to its apparent resistance.

$$f_A = \frac{b^2}{r'}$$

II. The apparent distance of the leak from the observer is equal to the square root of the product of the fall observed by the distant station and the apparent resistance of the leak observed by himself, or $\sqrt{f_B r''}$.

III. The D.R. of the cable is equal to the square of C.R. beyond the leak divided by the observed fall, or $r' = \frac{b^2}{f_A}$.

IV. The resultant leak is distant from each end inversely as the square roots of the falls.

The Author proposes to make weekly records of the positions of the resultant faults. Loop localisations should be obtained with the junction earthed, as the long electrification of free loops makes accuracy difficult.

M. O'G.

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Drop of Potential in the Electric Arc. Mrs. Ayrton.

(Electrician, vol. xli., 1898, p. 720.)

From the + carbon to the arc the drop $V = 31{\cdot}28 + \frac{9 + 3{\cdot}1\,l}{A}$.

From the − carbon to the arc the drop $V^1 = 7{\cdot}6 + \frac{13{\cdot}6}{A}$. As the exploring carbon influences the length and voltage of the arc an insulated exploring pencil is being made.

M. O'G.

Detecting Approach of Objects at Sea. H. Herberts.

(Electrical Engineer, N.Y., vol. xxvi., 1898, pp. 97–99.)

This proposed apparatus comprises two thermopiles arranged on a ship and caused to slowly rotate about a vertical axis. These thermopiles are arranged with their collecting cones facing opposite sides, and are each connected through sliding contacts with a d'Arsonval galvanometer; the moving coils of these galvanometers bear aluminium arms which, when the coil is deflected, complete one or other of two electric-bell circuits, according to the direction in which the current flows, that is to say, when the thermopile cone is directed towards a warm body, a vessel for example, one bell will give a short ring, whilst when it is directed towards a cold object, an iceberg for example, the other bell will give a short ring. The direction of the particular object is determined by means of an electrically operated pointer which rotates synchronously with the thermopiles. By watching the instantaneous position of the revolving pointer at the moment the bell rings, and simultaneously cutting out one of the thermopiles by a switch, an approximate knowledge of the direction of the object can be obtained. By introducing resistance into the thermopile circuits, the aluminium arm can be made to complete the bell-circuit only at the instant the maximum current is being produced, and thus the exact direction determined. By the increasing or diminishing action of the thermopiles, it can be determined whether the object is approaching or receding. Further details and diagrams of the apparatus and modifications thereof are given in the original Paper.

C. K. F.

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Westinghouse Electrical Turn-table "Donkey."

(Electrical Engineer, N.Y., vol. xxvi., 1898, p. 185.)

This round-house "donkey" comprises a series reversible 10 HP. motor mounted within a heavy cast-iron frame having a traction wheel which rests upon the rail of the turn-table pit and to which the power is transmitted through double reduction gears. The donkey-frame is connected by drawbar and pin to one end of the turn-table at the side, sufficient traction for the driving-wheel being secured by the weight of the machine, 3,700 lbs. It may be moved in either direction, and its speed varied by means of a switch and rheostat controlled by a single lever. No changes are required in the turn-table in order to instal the "donkey." With the turn-table light the donkey will make a complete revolution in 30 seconds, whilst with a 10-wheel locomotive and tender, weighing 100 tons, a complete revolution is made in 45 seconds. From actual tests it is stated that the power consumed is the equivalent of $\frac{1}{2}$ HP.-hour. Assuming 6 lbs. of coal per HP.-hour, with coal at $2 per ton, the cost of turning each locomotive would be $\frac{3}{10}$ of one per cent.

C. K. F.

Boiler-Feeding by Injectors. J. WHITCHER.

(Electrical Review, vol. xliii., 1898, pp. 303–304.)

The Author discusses boiler feeding by injectors and pumps. If a boiler at 140 lbs. working pressure be fed by a pump of 50 per cent. efficiency through a heater raising the temperature of the feed from 100° to 200° F., 1 lb. of steam will pump 100 lbs. of water, and the heat thrown away in the pump exhaust is 1,120 B.T.U., whereas the heat abstracted from the exhaust heater is 10,000 B.T.U. An injector will save the former quantity and reject the latter. Therefore it is bad policy to use an injector where feed heating is possible, and bad policy to use a pump unless in conjunction with a feed heater. Apart from the question of feed heating, the injector merits preference above all other appliances for boiler feeding. Better opinions regarding it would be obtained if two injectors of equal size and combined capacity, just slightly greater than the maximum rate of feed, were mounted independently, so that either could be easily dismantled during working hours.

A. S.

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Modern Brush-Holders.

(Electrical World, vol. xxxii., 1898, pp. 87–91.)

The Paper contains an interesting and fully illustrated description of the typical forms of brush-holders used in connection with the machines exhibited at the recent New York Electrical Show. Carbon brushes are used in every case, and in most holders are arranged to bear on the commutator in a radial direction (the tangent contact brush seems to have quite disappeared). It is impossible to adequately abstract the Paper without a large number of sketches.

[An illustrated abstract appeared in *The Electrician*, 1898, vol. xliv., pp. 616–618.]

A. H.

Commutator Segments. F. X. Cicott.

(Railway World, vol. vii., 1898, pp. 81–84.)

The Author draws attention to the disadvantages of cast copper segments, and describes the process of drop-forging commutator segments. A cylindrical rod of copper of the size bar required is heated to a malleable state in an oil furnace producing a uniform heat, and while in that state the rod is bent to form, then passed for the action of dies in the drop-press and stamped, which produces an unfinished segment of the designed shape. This is treated with acid to remove the oxide. The rough edges are trimmed, and the bars cold-dropped to bring them to the required gauge. Hard-drawn copper segments are also used in America. The General Electric Co. of Schenectady use hard-drawn only. The Paper contains a table of angles of segments for commutators of 4 to 150 parts. The Author concludes by remarking that the use of wrought copper should be seriously considered by the European manufacturers.

R. B. R.

Transformer Regulation. F. Bedell.

(Electrical World, vol. xxxii., 1898, pp. 364–365.)

The Author gives working formulas for determining the regulation drop in lighting and power transformers.

The secondary load in lighting transformers is non-inductive, and the effective reactance drop is

$$\frac{x^2 + 2xi\mu}{200}$$

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where x is the per cent. reactance drop and $i\mu$ the per cent. exciting current, magnetizing component. The secondary load in power transformers is inductive, and the drop is now

$$c \cos \delta + x \sin \delta$$

where c is the per cent. resistance and cos δ the power factor.

W. G. R.

Cost of Steam and Water Power. W. O. Webber.

(Engineering Magazine, vol. xv., 1898, pp. 922–927.)

The Author estimates the present cost of operating a 1,000-HP. steam plant as follows:—

	Dollars per HP. per annum.
Interest on capital, depreciation, repairs, &c.	6.55
Coal (1·4 lb. per I.H.P. hour, at 3·85 dols. per ton)	7.41
Wages (two engineers, two stokers)	3.08
Oil, waste, &c.	0.80
Total	17.84

i.e., £3 14*s.* 4*d.* per HP. per annum.

The actual return from the best plant known to the Author gives a total cost of $11.64 per HP. per annum, the coal costing $1.76 per ton. The plant consists of a vertical, cross-compound, condensing engine by the E. P. Allis Company, the load averaging 1,950 HP. The steam pressure is 155 lbs. per square inch. The boilers are of the Heine water-tube pattern; an exhaust steam heater and a Green economiser are used.

The actual cost of a small water-power plant consisting of three wheels giving a maximum of 510 HP. is $5.56 (£1 3*s.* 3*d.*) per HP. per annum, the average power being taken at 315 HP.

A. S.

Three-Phase Installation at the Bristol Wagon and Carriage Works. W. Geipel.

(Electrical Review, vol. xliii., 1898, pp. 427–429.)

This is a Paper read before the British Association, and deals principally with the saving of power effected by using electric motors for driving machines instead of a multiplicity of steam engines in a works of wide area. At the Bristol Wagon Works five Lancashire boilers have been necessary for driving the engines; with electric power plant one Lancashire boiler will suffice, and

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the saving of coal is estimated at 37 tons per week. The three-phase system has been adopted for the electric plant for the following reasons:—

1. Absence of commutators on both generator and motors.
2. The more mechanical design and construction of the generator and motors, the windings of the latter, being entirely enclosed by the iron frame of the machine, protecting them from accidental damage.
3. The fact that the three-phase motors can be left running for long periods without any attention, which is not advisable in the case of direct-current motors.
4. The freedom from possibility of breakdown as compared with the direct-current system.

W. G. R.

Glasgow Electric Tramways.

(Electrician, vol. xlii., 1898, pp. 104–109.)

Two and a half miles of track between Glasgow and Springburn have been experimentally equipped with trolley system; 100-lb. rails, rolled in 45-feet lengths by the Barrow Steel Company, are bonded with Daniel bonds. The poles, overhead equipment, and cars were all made in Great Britain. Where centre poles are used, the trolley wire is carried on fiddle-string supports, which give an easier passage to the trolley wheel than the ordinary rigid American support. Section boxes at every ½ mile connect through switches to the feeders, and also contain lighting arresters and telephones. Each of the twenty-five cars (mostly single decked) has two 55-HP. motors of the usual American pattern. Important experiments on electric brakes are in progress. The power station is independent from the lighting station and contains Babcock boilers, Vicar's coking stokers, McIntosh and Seymour engines, and Westinghouse generators rated at 200 kilowatts, also a standard Westinghouse switchboard. A cooling-tower with fan draught is used for the condensing water. Cars are run with 2½ minutes headway at an average speed of 7 miles per hour.

E. H. C.-H.

Cost of Electrical Energy for Tramways. R. W. Conant.

(Engineering News, vol. xl., 1898, pp. 181–183.)

This is an analysis of the results obtained at forty-four power stations during the past year. The Author adopts the kilowatt-hour in preference to the car-mile as a standard of reference, and compares the working of the various stations with that of a

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standard station operating under the most favourable conditions. The equipment of the standard station is assumed to consist of three 1,200-kilowatts steam dynamos and six 500-HP. water-tube boilers, with the usual accessories, the estimated costs being approximately as follows:—

	£
Buildings, foundations for machinery, chimney, coal handling apparatus, &c.	25,000
Engines and condensers, heaters, separators and piping	19,135
Feed pumps and economisers	3,750
Boilers and flues	12,700
Generators and switchboard	15,375
Land and docking facilities	3,540
Engineering and sundries	1,040
Total	£80,540
Cost per kilowatt capacity	£22·4

On the basis of an annual output of 10,500,000 kilowatt-hours, with a load factor of 33·3 per cent., the working expenses are:—

	d.
Interest, depreciation and taxes	0·20
Labour	0·08
Fuel at 14/- per ton	0·16
General expenses	0·05
Total per kw.-hour	0·49

Simple rules and diagrams are given for finding the costs of labour and fuel under various conditions of price of coal and labour, load factor, efficiency, &c. Other diagrams and tables show the actual cost of the respective items at several selected stations at different seasons, compared with the values estimated for the standard station. Usually the fixed charges, cost of fuel, cost of labour, and general expenses, are roughly in the ratio 4 : 4 : 2 : 1. The items of expense in some of the cases are discussed and explained. At three existing stations the working cost per kilowatt-hour is less than that given for the standard station.

A. H. A.

Siemens and Halske Conduit Systems. G. Braun.

(Electrical World, vol. xxxii., 1898, pp. 392–395. Abstracted from Elektrotechnische Zeitschrift.)

In the Budapest system there is an egg-shaped concrete conduit under one rail, containing two angle-bar conducting rails, one at each side of the conduit, fastened to the yokes by means of insulators. The yokes, placed at a distance of 1·2 metre, support and maintain at the proper distance from each other the two halves of

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the tram rail, which serves also as a slot rail, *i.e.*, the slot is not midway between the rails but coincides with the groove of one of them. The wheel flange is in the middle of the tire. The pick-up device is two cast-iron shoes attached to a plough and pressing laterally outwards into the angle of the conducting rails. The conduits drain to sumps and are cleared out by egg-shaped shifters attached to a plough. As compared with American conduit practice the Budapest system has the advantage that less iron is required on the surface of the street. Points are a difficulty owing to necessity for retaining the full sectional profile of both the conduits. Diagrams show the devices adopted. To facilitate rapid change from conduit to trolley the plough is automatically ejected at the required point by an inclination in the floor of the conduit. In 1896, 4,000,000 car-kilometres were run in Budapest on this system. In Germany a similar system with ground return is being used. The conduits are completely interrupted at points and crossings, the ploughs being automatically ejected and then reinserted.

E. H. C.-H.

Bow Form of Trolley. STOBRAWA.

(Électricien, vol. xvi., 1898, pp. 97–100.)

To reduce the weight of the bow it is now frequently made of aluminium with white-metal rubbing surfaces. The old square form has given place to the triangular form, which makes it impossible for the wire to lodge underneath the bow, when it is liable to wreck the overhead system. In Dresden the life of a bow covered with white-metal is about two weeks, while if made of aluminium it lasts eight weeks, corresponding to about 8 car-kilometres. The cost of maintenance works out at Basle and at Dresden at 0·0875 centime per car-kilometre. Use of an annular contact-surface facilitates the use of a lubricant which has the double advantage of making the sliding noiseless and rendering easy the removal of ice in winter. In Dresden the tension on the springs is specified not to exceed 3·5 kilograms. At curves an extra wire is used to prevent the bow striking cross-wires. After four years' use it was found that the section of trolley wire was reduced to 96 per cent. of the original, owing to friction of the bow, but in this particular the bow is superior to the trolley, as the latter also wears the side of the wire at curves. In the case of a bow the extra wear at curves falls on the additional guiding wire, which is easily replaced.

E. H. C.-H.

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Single- and Double-Truck Cars. R. McCulloch.

(Electrical Engineer, N.Y., vol. xxvi., 1898, pp. 251–254.)

Twenty-two feet is about the limiting length of body of a single-truck car: beyond this length double trucks must be used to avoid oscillation and grinding on curves. The expenses of the average city road may be divided up as follows: maintenance of way and structures, 4 per cent.; maintenance of equipment, 7 per cent.; conducting transportation, 52 per cent.; general expenses, 8 per cent.; fixed charges, 29 per cent. If the number of cars be reduced by increasing them in size the heaviest item (viz., conducting transportation) will be reduced almost in proportion. Detailed tables are given comparing single and double trucks on the following points: (1) Cost of wheels and brake-shoes per annum. (2) Repairs of trucks and motors. (3) Power required. (4) Weights carried empty and full. Taking into account the number of passengers carried, it appears that the costs under these various headings are about equal for single and double trucks. The trouble with maximum traction trucks getting off the line was due to the small weight put upon the trailers. Thirty per cent. of the weight is now put on the small wheels. In the discussion on this Paper J. I. Beggs mentioned that at Milwaukee ten interurban cars were in use, equipped with four "G.E. 1,000" motors geared to 26 miles per hour, weighted with 40,000 lbs., the cars weighing about 35,000 lbs.

E. H. C.-H.

Electric Train Lighting.

(Railroad Gazette, vol. xxx., 1898, pp. 668–669.)

The Stone system of lighting railway trains by means of accumulators and a dynamo driven from the axle of the guard's van is described. The dynamo is so suspended that the tension of the belt cannot exceed a certain prearranged limit, beyond which the belt slips on the pulley, while the armature is driven at a constant speed. A mechanical governor switches the accumulators off when the train slackens speed. Experiments show that the dynamo speed is constant while the speed of the train varies from 24 to 72 miles per hour. The power absorbed is from 0·6 to 1·1 HP. for an ordinary coach, consuming about 0·05 lb. coal per coach per mile.

A H. A.

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Fig.ª 5.

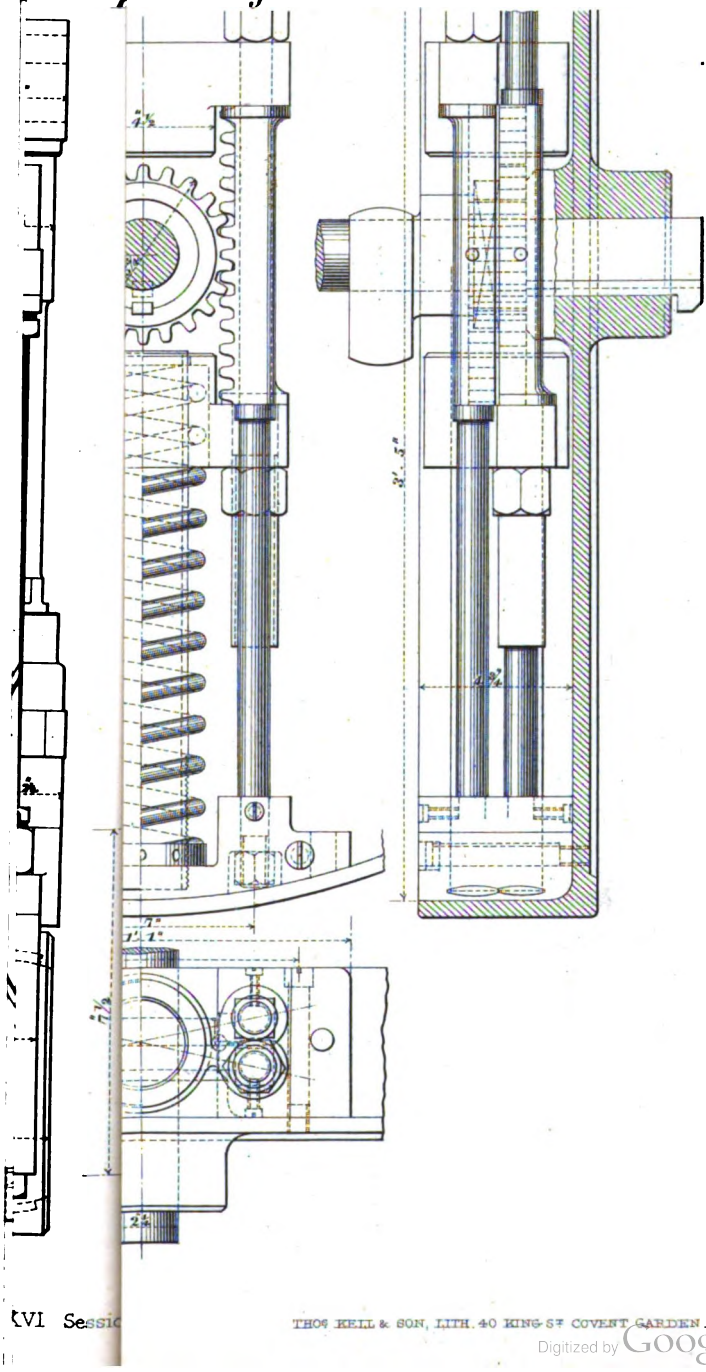

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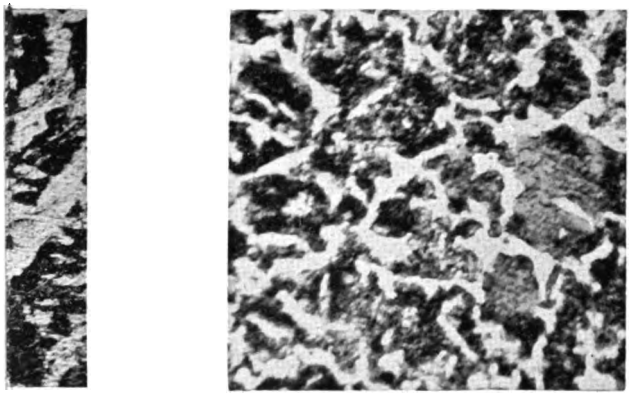
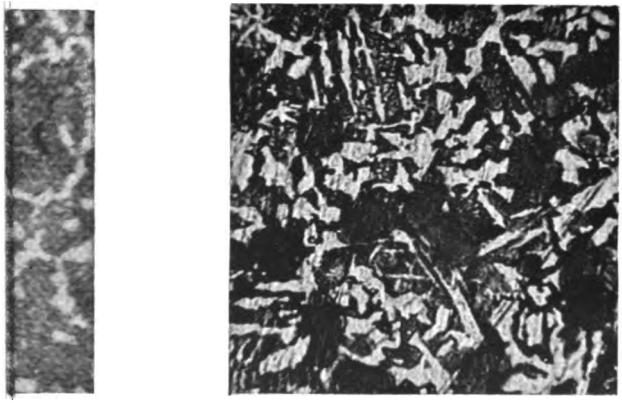
Fig. 3.



Carbon.....0·40%
Manganese .....0·90

ve rails in small quantities.
0·09% and 0·20%
0·06 ,, 0·08
0·04 ,, 0·09

Fig. 6.



Carbon.....0·40%
Manganese .....0·47

d in relief and stained with an infusion of liquorice.

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Fig. 19.

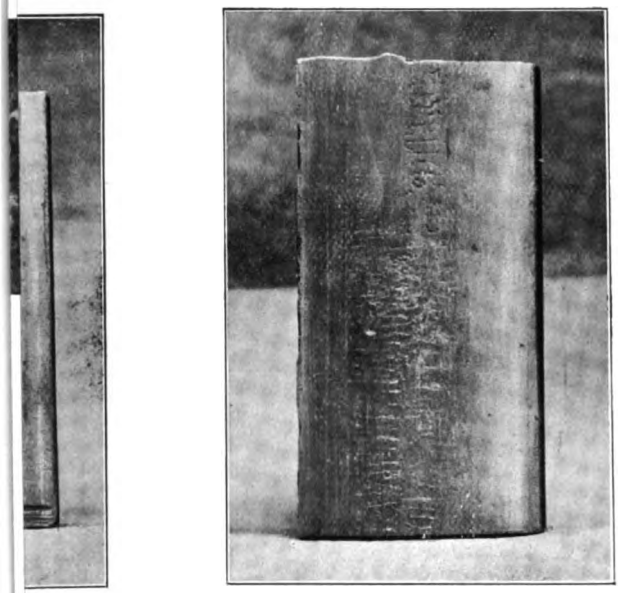

Fig. 21.

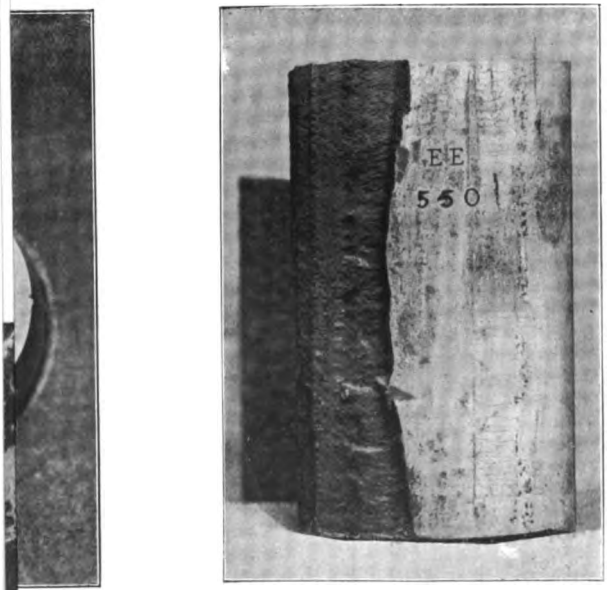

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Fig. 35.

Fig. 37.

Figs. 3

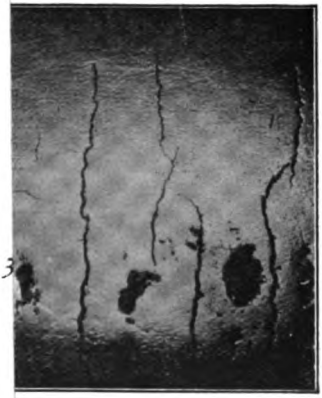

Fig. 39.

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ig: 8.

OUTER ENT

NEL

BRIDGE.

Fig: 13.

CE CHANNEL.

N. INNER PORTION.

2 to 1.

3 to 1.

82. 0"

14.

BASIN.

2 to 1.

3 to 1.

15.

ANAL.

2 to 1.

3 to 1.

Fig: 16.

PORT OF BRUGES.

150 Feet.

200 Feet.

OUTER BASIN.

EAST BASIN.

WEST BASIN.

OSTEND AND BRUGES CANAL.

65'. 8"

LOCK CHA

Fig: 9.

ACROSS LO AMBER.

LUIS CANAL.

H. W.

L. W.

OCKS.

100 Feet.

40 50 Feet.

ISSON.

Fig: 12.

H.W.

L.W.

18'. 1"

16'. 3"

ig: 7.

LAN.

ECTION.

CROSS SECTION.

II.

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IUM .

LLS .

0 Scale 20 0 10 20 30

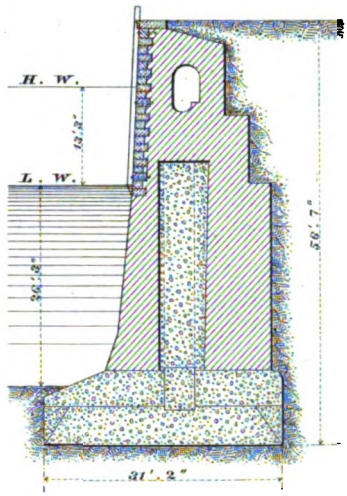
Fig

PORT OF

XTENSION

Fig: 21.

ANTWERP QUAY WALL,
IN PROGRESS.



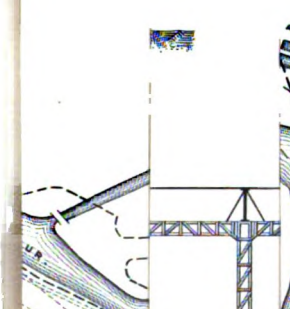
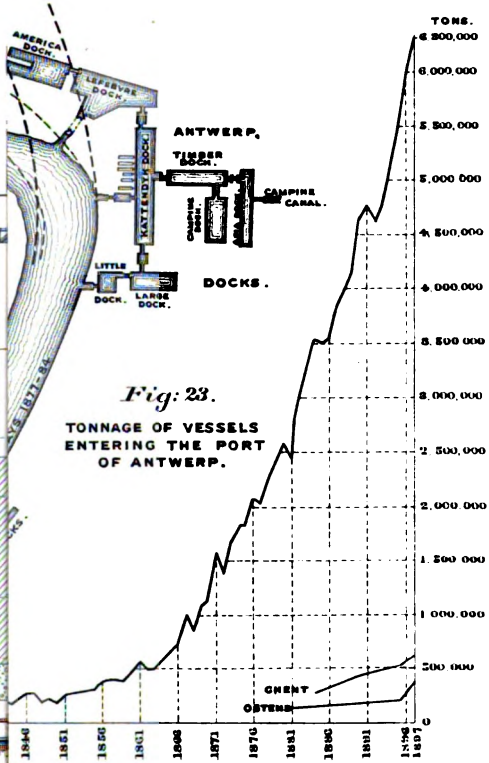


Fig: 23.

TONNAGE OF VESSELS
ENTERING THE PORT
OF ANTWERP.



TION .

art II

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